PB-222 773

# IRRIGATION MANAGEMENT FOR CONTROL OF QUALITY OF IRRIGATION RETURN FLOW

Larry G. King, et al

Utah State University

Prepared for:

Environmental Protection Agency

June 1973

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 222 773

**EPA-R2-73-265**
**June 1973**

**Environmental Protection Technology Series**

W73-13469

# Irrigation Management For Control of Quality of Irrigation Return Flow

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. Department of Commerce
Springfield VA 22151

**Office of Research and Monitoring**
**U.S. Environmental Protection Agency**
**Washington, D.C. 20460**

321

## RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

SELECTED WATER
RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

W 73-13469

IRRIGATION MANAGEMENT FOR CONTROL OF QUALITY
OF IRRIGATION RETURN FLOW,

King, L.G. and Hanks, R.J.

Utah State University, Logan, Department of
Agricultural and Irrig tion Engineering

EPA Project 13030 FDJ

~~EPA 13030 FDJ~~

Environmental Protection Agency, Technology Series report ~~number~~,
EPA-R2-73-265, June 1973. 307 p, 81 fig, 60 tab, 15 ref

Field studies tested the possibilities for using the unsaturated soil profile including the crop root zone as a temporary salt reservoir and providing excess water for leaching and salt discharge when desired. Two models were developed for describing flow of water and salt through the soil with extraction of water by evapotranspiration. One model was designed for use as an irrigation management tool while the other model was initially intended to provide a detailed understanding of the water and salt flow through the soil. The best management model will probably result from a combination of the two models described ~~in this report~~. Timing of irrigation was tested as a management variable. With all other conditions the same, the model predicts that as the time interval between irrigations increases, the season totals of salt removed from the root zone, salt remaining in the profile, and water required for leaching tend to level off. However, the irrigation frequency has a significant effect upon when the salt is discharged during the season. Results indicate that managing irrigation for control of return flow quality requires good control of depth and timing of irrigation. Some needs for further research are given ~~in the report. (King-Utah State)~~ (EPA)

*Return flow, *Leaching, *Salinity, *Irrigation practices, *Colorado River Basin, Environmental effects, Water quality, Irrigation, Drainage, Soil water, Management, Drainage effects, Computer models, *Model studies, *Utah

*Return flow quality, *On-farm water management, *Salt storage, *Irrigation scheduling, Salt movement, Irrigation frequency, Irrigation management, Field irrigation studies, Ashley Valley ~~Vernal~~ (Utah)

02G, 05G, 05B, 03C

73-265
Copy available from GPO Sup Doc
as EP1.23/2: $3.45 ; microfiche
from NTIS as PB [illegible], ~~$0.95.~~ 1.45

Send To:

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D.C. 20240

Larry G. King | Utah State University

ia

EPA-R2-73-265
June 1973

# IRRIGATION MANAGEMENT FOR CONTROL OF QUALITY OF IRRIGATION RETURN FLOW

by

Larry G. King
R. John Hanks

Utah State University
Logan, Utah 84322

Project #13030 FDJ
Program Element #1B2039

Project Officer

Dr. James P. Law, Jr.
U. S. Environmental Protection Agency
Robert S. Kerr Environmental Research Laboratory
P. O. Box 1198
Ada, Oklahoma 74820

Prepared for

OFFICE OF RESEARCH AND MONITORING
U. S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D. C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price $3.45 domestic postpaid or $3 GPO Bookstore

## EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

AS NOTED IN THE NTIS ANNOUNCEMENT, PORTIONS OF THIS REPORT ARE NOT LEGIBLE. HOWEVER, IT IS THE BEST REPRODUCTION AVAILABLE FROM THE COPY FURNISHED NTIS BY THE CONTRIBUTOR.

# ABSTRACT

Maintaining irrigated agriculture on a permanent basis is impossible without some deterioration of quality of water as it moves through the soil to the groundwater and eventually returns to the stream. Even if all salt loading could be eliminated, the concentrating effect would remain because the process of evapotranspiration extracts nearly pure water leaving the salts behind. Control over irrigation return flow quality is desirable. One possibility for control might be to use the unsaturated soil profile including the crop root zone as a temporary salt reservoir and provide excess water for leaching and salt discharge when desired. Such control requires detailed knowledge of water and salt movement through the root zone of the crops.

Two models were developed and tested in the field for describing flow of water and salt through the soil with extraction of water by evapotranspiration. One model was designed for use as an irrigation management tool while the other model was initially intended to provide a detailed understanding of the water and salt flow through the soil. The best management model will probably result from a combination of the two models described in this report.

Timing of irrigation was tested as a management variable. With all other conditions the same, the model predicts that as the time interval between irrigations increases, the season totals of salt removed from the root zone, salt remaining in the profile, and water required for leaching tend to level off. However, the irrigation frequency has a significant effect upon when the salt is discharged during the season. Results indicate that managing irrigation for control of return flow quality requires good control of depth and timing of irrigations. Some needs for further research are given in the report.

# CONTENTS

| Section | | Page |
|---|---|---|
| I | Conclusions | 1 |
| II | Recommendations | 3 |
| III | Introduction | 7 |
| IV | Review of Literature | 11 |
| V | Development of Models | 25 |
| VI | Testing of Models | 59 |
| VII | Use of Models for Irrigation Management | 163 |
| VIII | Summary | 177 |
| IX | Acknowledgments | 183 |
| X | References | 185 |
| XI | Publications Resulting From Project | 191 |
| XII | Appendices | 193 |

Preceding page blank

# FIGURES

No. Page

1 Typical layer of soil in simplified model. 27

2 Location map, Hullinger farm, Vernal, Utah. 60

3 Farm layout. 61

4 Pressure potential vs water content for Mesa sandy loam soil. Condition A was used in the computation. Condition B was used to test the sensitivity of the model. 79

5 Water content vs hydraulic conductivity for Mesa sandy loam soil. 80

6 Variation of Ca-Mg exchange coefficient with solution concentration (a) surface soil, (b) subsoil. 83

7 Variation of Ca-Na exchange coefficient with solution concentration (a) surface soil, (b) subsoil. 84

8 Measured values (points) of leaching factor at three initial moisture contents compared with curves calculated from the leaching factor function. 91

9 Logarithmic plot of leaching factor vs effluent ratio used to develop the leaching factor function showing measured values (points) compared to curves calculated from the resulting leaching factor function. 93

10 Upper limit of field moisture, $\theta_{fm}$, in each soil layer in Block 5 as determined from moisture content measured 9.5 and 33.5 hours after an irrigation ended (measured values are averaged from 5 locations). 106

11 Comparison of measured (M) and calculated (C) profiles of moisture content, $\theta$, and electrical conductivity of soil solution, $EC_s$, for Block 3. 109

## FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 12 | Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, for Block 5. | 110 |
| 13 | Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, for Block 6. | 111 |
| 14 | Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, for Block 7. | 112 |
| 15 | Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, after adjusting moisture extraction pattern to minimize differences in calculated and measured θ profiles for Block 3. | 117 |
| 16 | Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, after adjusting moisture extraction pattern to minimize differences in calculated and measured θ profiles for Block 5. | 118 |
| 17 | Measured (M) $EC_s$ for Block 3 compared with calculated (C) values resulting from letting ER = 0.5 ER, ER is effluent ratio. | 119 |
| 18 | Measured (M) $EC_s$ for Block 5 compared with calculated (C) values resulting from letting ER = 0.5 ER, ER is effluent ratio. | 119 |
| 19 | Water flux at the surface (evapotranspiration and precipitation, cm/hr) vs time for oats in the 9-day interval in 1970. | 121 |

FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 20 | Comparison of the water content profiles as predicted (dotted) and measured (solid) for oats in 1970. (a) 24 hrs, (b) 72 hrs, (c) 120 hrs, (d) 216 hrs | 122 |
| 21 | Comparison of water content profiles as measured (solid) and predicted (dotted) for crop 1 alfalfa in 1971. (a, c) 24 hrs after precipitation, (b, d) end of irrigation interval. | 124 |
| 22 | Comparison of water content profiles as measured (solid) and predicted (dotted) for crop 2 alfalfa in 1971. (a, c) 24 hrs after irrigation, (b, d) end of irrigation interval. | 125 |
| 23 | Comparison of water content profiles as measured (solid) and predicted (dotted) for crop 3 alfalfa in 1971. (a) end of irrigation interval, (b) 24 hrs after irrigation, (c) 48 hrs after irrigation, (d) end of irrigation interval. | 126 |
| 24 | Comparison of measured (dots) and predicted (solid lines) water content profiles for alfalfa in 1971. (a) 30 cm, (b) 70 cm, (c) 100 cm depth. | 127 |
| 25 | Comparison of actual, predicted, and potential evapotranspiration during the 9-day period with that predicted for oats in 1970. | 128 |
| 26 | Variation of actual ET/Penman E for alfalfa in 1971. | 129 |
| 27 | Variation of root water potential of alfalfa in 1971. The increase in Hroot is due to precipitation. (a) crop 1, (b) crop 2, (c) crop 3. | 131 |
| 28 | Comparison of actual (dots) and predicted (solid line) upward flow from the water table for oats during the 9-day interval in 1970. | 132 |
| 29 | Comparison of actual (dots) and predicted (solid line) upward flow of water from the water table for alfalfa in 1971. | 133 |

FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 30 | Hroot during the 9-day period as predicted from 30, 45, and 70 cm root distribution. | 135 |
| 31 | Comparison of measured water content profiles for soil condition A and B at the end of the 9-day period in 1970, oats. | 136 |
| 32 | Comparison of measured and predicted water content profiles at the end of a 9-day period in 1970 assuming root distribution 30, 45, and 70 cm. | 138 |
| 33 | Comparison of water content profiles as predicted, θ was initialized after each hay cut (dots), θ was initialized at the beginning of the season (solid lines); (a, c) three days after hay cut, (b, d) at the end of the crop. | 140 |
| 34 | Cumulative evapotranspiration vs time compared with predicted evapotranspiration where the lower limit of Hroot was -40 bars and -20 bars (data for desert soil from Curlew Valley, Utah). | 141 |
| 35 | Relative root extraction of alfalfa as a function of time after irrigation and depth. | 143 |
| 36 | Comparison of predicted (dotted) and measured (solid) water content and total salt concentration profiles for conditions of Case #1. | 144 |
| 37 | Comparison of predicted (dotted) and measured (solid) ion concentration profiles for conditions of Case #1. | 145 |
| 38 | Comparison of predicted (dotted) and measured (solid) water content and total salt concentration profiles for conditions of Case #2. | 147 |
| 39 | Comparison of predicted (dotted) and measured (solid) ion concentration profiles for conditions of Case #2. | 149 |

FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 40 | Comparison of predicted (dotted) and measured (solid) water content and total salt concentration profiles for conditions of Case #3. | 150 |
| 41 | Comparison of predicted (dotted) and measured (solid) ion concentration profiles for conditions of Case #3. | 151 |
| 42 | Comparison of predicted (dotted) and measured (solid) water content profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. | 153 |
| 43 | Comparison of saturation extract (solid) and soil solution (dotted) electrical conductivity profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. | 154 |
| 44 | Comparison of predicted (dotted) and measured (solid) total salt concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown. | 155 |
| 45 | Comparison of predicted (dotted) and measured (solid) calcium concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown. | 156 |
| 46 | Comparison of predicted (dotted) and measured (solid) magnesium concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown. | 157 |
| 47 | Comparison of predicted (dotted) and measured (solid) sodium concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown. | 158 |
| 48 | Comparison of predicted (dotted) and measured (solid) chloride concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown. | 160 |

FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 49 | Predicted drainage and salt concentration of the drainage water over a period of 627 hrs. | 161 |
| 50 | Generally increasing concentrations of irrigation water in mmho/cm during the growing season. (The circled values are the concentrations at each irrigation). | 165 |
| 51 | Generally decreasing concentrations of irrigation water in mmho/cm during the growing season. (The circled values are the concentrations at each irrigation). | 166 |
| 52 | Season totals of salt existing, salt leaving, water applied, and leaching water as functions of irrigation frequency for problem ACF. | 172 |
| 53 | Season totals of salt existing, salt leaving, water applied, and leaching water as functions of irrigation frequency for problem BCF. | 173 |
| 54 | Results of problem ACF for each irrigation of the season for 8 and 20 days between irrigations. | 174 |
| 55 | Results of problem BCF for each irrigation of the season for 8 and 20 days between irrigations. | 175 |
| 56 | Hydrograph of discharge from drain 4 during 1971. | 283 |
| 57 | Hydrograph of discharge from drain 5 during 1971. | 284 |
| 58 | Hydrograph of discharge from drain 3 during 1971. | 285 |
| 59 | Hydrograph of discharge from drain 6 during 1971. | 285 |
| 60 | Season total results for problem ACG. | 286 |
| 61 | Season total results for problem BCG. | 287 |
| 62 | Season total results for problem ACH. | 288 |
| 63 | Season total results for problem BCH. | 289 |

FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 64 | Season total results for problem ACI. | 290 |
| 65 | Season total results for problem BCI. | 291 |
| 66 | Season total results for problem ADF. | 292 |
| 67 | Season total results for problem BDF. | 293 |
| 68 | Season total results for problem ADG. | 294 |
| 69 | Season total results for problem BDG. | 295 |
| 70 | Season total results for problem ADH. | 296 |
| 71 | Season total results for problem BDH. | 297 |
| 72 | Season total results for problem ADI. | 298 |
| 73 | Season total results for problem BDI. | 299 |
| 74 | Season total results for problem AEF. | 300 |
| 75 | Season total results for problem BEF. | 301 |
| 76 | Season total results for problem AEG. | 302 |
| 77 | Season total results for problem BEG. | 303 |
| 78 | Season total results for problem AEH. | 304 |
| 79 | Season total results for problem BEH. | 305 |
| 80 | Season total results for problem AEI. | 306 |
| 81 | Season total results for problem BEI. | 307 |

## TABLES

| No. | | Page |
|---|---|---|
| 1 | Summary of results from laboratory technique of soil calibration to determine leaching factor (LF) for Hullinger farm soil. | 30 |
| 2 | Results of calibration of the neutron probe. | 66 |
| 3 | Irrigation schedules for various irrigation blocks on the Hullinger farm between first and second cuttings of alfalfa in 1971. | 70 |
| 4 | Irrigation schedules for various irrigation blocks on the Hullinger farm between second and third cuttings of alfalfa in 1971. | 71 |
| 5 | Initial conditions for field experiments. | 74 |
| 6 | Boundary condition in the field experiment for soil water and salt flow. Started August 17, 1971. | 75 |
| 7 | Chemical composition of irrigation water. | 76 |
| 8 | Initial soil conditions for column experiments. | 77 |
| 9 | Concentrations (EC in mmho/cm) used to determine LF. | 86 |
| 10 | Leaching factor for various effluent ratios (Mesa sandy loam, 6.0 inch samples) for initial moisture content of 0.20 (volumetric). | 87 |
| 11 | Leaching factor for various effluent ratios (Mesa sandy loam, 6.0 inch samples) for initial moisture content of 0.15 (volumetric). | 89 |
| 12 | Leaching factor for various effluent ratios (Mesa sandy loam, 6.0 inch samples) for initial moisture content of 0.05 (volumetric). | 90 |
| 13 | Volumetric moisture content ($\theta$) measured by neutron meter on dates of soil sampling. | 96 |

TABLES (Continued)

| No. | | Page |
|---|---|---|
| 14 | $EC_e$ of the top one foot of soil at six sites within each irrigation block as determined from soil samples taken on June 22, August 3, and September 9. | 97 |
| 15 | Analysis of variance for $EC_e$ of soil samples from the top one foot of soil taken on June 22, August 3, and September 9. | 98 |
| 16 | Irrigation schedule and depth and EC of irrigation water for Block 3 during the evaluation period. | 100 |
| 17 | Irrigation schedule and depth and EC of irrigation water for Block 4 during the evaluation period. | 101 |
| 18 | Irrigation schedule and depth and EC of irrigation water for Block 5 during the evaluation period. | 102 |
| 19 | Irrigation schedule and depth and EC of irrigation water for Block 6 during the evaluation period. | 103 |
| 20 | Irrigation schedule and depth and EC of irrigation water for Block 7 during the evaluation period. | 104 |
| 21 | The upper limit of field moisture ($\theta_{fm}$) for each soil layer and irrigation block. | 107 |
| 22 | Net upward movement of water into the soil profile, as determined from total irrigation water applied, total ET, and soil moisture measurements. | 113 |
| 23 | Percent moisture extracted by plant roots that is required to match calculated moisture content profiles to corresponding measured profiles. | 115 |
| 24 | Comparison of predicted evapotranspiration, evaporation, transpiration, and water flow as influenced by different soil properties for a nine-day period starting July 28, 1970 at Vernal, Utah (no precipitation). | 137 |

## TABLES (Continued)

| No. | | Page |
|---|---|---|
| 25 | Comparison of evapotranspiration, upward flow of water from the water table and Hroot at the end of the nine-day interval in 1970. | 137 |
| 26 | Effect of change in upper boundary condition and root depth on evaporation, transpiration and upward water flow (11 days). | 139 |
| 27 | Concentration constraints for each soil layer used in hypothetical problem. | 164 |
| 28 | Depth in inches of water applied during each irrigation. | 164 |
| 29 | Salt leaving the root zone in tons per acre for each irrigation. | 167 |
| 30 | Depth in inches of leaching water required for each irrigation. | 167 |
| 31 | Salt leaving the root zone in tons per acre for each irrigation when the depth of water applied is input. | 168 |
| 32 | Concentration of the soil solution in millimhos per centimeter after each irrigation interval when the computed concentration exceeded the critical concentration. | 169 |
| 33 | Values of irrigation water EC, initial $EC_s$, and concentration constraints used in simplified model for solution of 24 problems. (mmho/cm) | 171 |
| 34 | Rain, irrigation and actual evapotranspiration data for alfalfa in 1971. Rain and irrigation data were measured by rain gauge, evapotranspiration data were measured by the lysimeter. | 239 |
| 35 | Average soil water content ($\theta$) of six sites in the field, as measured by the neutron probe, and equivalent depth of water in the soil profile for alfalfa in 1971, and for oats in 1970. | 243 |

TABLES (Continued)

| No. | | Page |
|---|---|---|
| 36 | Average soil water content (θ) of two sites in two lysimeters as measured by the neutron probe, and equivalent depth of water in the soil profile for alfalfa in 1971. | 244 |
| 37 | Average soil water content (θ) of four sites in the field, as measured by the gamma probe, for alfalfa in 1971. | 245 |
| 38 | Average soil water content (θ) of two sites in two lysimeters as measured by the gamma probe, for alfalfa in 1971. | 246 |
| 39 | Climatic data and potential evapotranspiration as calculated by Penman modified method for alfalfa in 1971. | 247 |
| 40 | Electrical conductivity (mmho/cm) of drain effluent measured periodically in the field with a portable conductivity meter in 1971. | 252 |
| 41 | Typical composition of Drain 5 effluent collected at one-hour intervals on August 4, 1971. | 254 |
| 42 | Piezometric data typical of conditions during the irrigation season on the Hullinger farm (6-29-71). | 255 |
| 43 | Piezometric data typical of early spring conditions on the Hullinger farm (5-4-71). | 257 |
| 44 | Electrical conductivity of the soil solution ($EC_s$) as calculated from average values of electrical conductivity of saturation extract ($EC_e$), soil water content by weight at saturation ($W_e$), and from field water content by weight (W), which was obtained from the average volumetric moisture content (θ) of each layer and from bulk density determinations. | 259 |
| 45 | Typical composition of salts in Hullinger farm soils. | 261 |

TABLES (Continued)

No. Page

46 Typical composition of groundwater samples from observation holes. 262

47 Field measurements of EC (μmhos/cm) of groundwater samples from observation holes. 263

48 Field measurements of EC (μmhos/cm) of groundwater samples from selected piezometers. 265

49 Average values of transmissability, T, hydraulic conductivity, K, specific yield, V, and $\alpha$ from constant discharge test. $\alpha = T/V$. 268

50 Values of hydraulic conductivity, K, by auger-hole method and corresponding specific yield, V, from Figure 7 of Dumm (1968). 268

51 Soil properties used for computations made. Mesa sandy clay loam soil. 269

52 Root distribution (RDF), salt content (SE) for alfalfa in 1971 and initial water content for alfalfa crop 1 ($\theta_1$), crop 2 ($\theta_2$), crop 3 ($\theta_3$) versus depth used for the computations made. 272

53 Root distribution (RDF), assumed for oats in 1970 with initial electrical conductivity (SE), and initial water content ($\theta_o$) versus depth. 273

54 Flux at the surface for alfalfa in 1971, evapotranspiration (ET), soil surface flux (WF), positive values are precipitation, negative values are evaporation, and salt concentration (SF) versus time. 274

55 Measured bulk density, water content, electrical conductivity, and ion concentration profiles for conditions of Case #1. 278

TABLES (Continued)

| No. | | Page |
|---|---|---|
| 56 | Measured bulk density, water content, electrical conductivity, and ion concentration profiles for conditions of Case #2. | 279 |
| 57 | Measured bulk density, water content, electrical conductivity, and ion concentration profiles for conditions of Case #3. | 280 |
| 58 | Chemical analyses of saturation extract for field experiment. | 281 |
| 59 | Water content (θ) profiles for salt flow field experiment. | 282 |
| 60 | Electrical conductivity (μmho/cm) profiles at the field water content for the salt flow field experiment. | 282 |

# SECTION I

## CONCLUSIONS

The models developed and described in this report can be used to investigate the possibility of exercising some control over irrigation return flow quality by proper irrigation management. In order to fully assess the possibilities, further model development and testing is needed. The simplified model is well suited for investigating a rather wide range of management variables because of very small computer time required. However, as pointed out in the body of the report, some field situations may not be adequately described with the simplified model in its present form. Its most notable limitation is the inability to handle upward flow from the water table.

The detailed model does an excellent job of predicting moisture movement in the field. Its ability to predict salt movement needs improvement. The model describes total salt movement better than movement of individual ions. It was concluded that the best management tool would probably result from a combination of the two models. Model development and field evaluation should continue.

The concept of temporarily storing salt in the soil profile appears to have merit. Timing of irrigations was tested as a management variable and found to have a significant effect upon water and salt movements. With all other conditions the same, the model predicts that as the frequency of irrigation decreases (time interval between irrigations increases), the season totals of salt removed from the soil profile, salt remaining in the profile, and water required for leaching tend to level off. That is, there is a fairly wide range of irrigation frequencies which would be practical to use in the field which do not change seasonal totals to any significant extent. However, the irrigation frequency has an important effect upon when during the season the salt is removed from the soil profile. Under conditions tested, the less frequent irrigation tend to release salt earlier in the season. The above results were obtained by not allowing the electrical conductivity of the soil water to exceed certain constraints.

The results indicate that control over quality of soil profile effluent will require precise control of water on the farm, particularly the depth and timing of irrigations. Some of the costs of establishing adequate systems could result in benefits other than increased control of water quality. Not the least of such benefits could be increased yield and quality of crops. To maintain the control over return flow quality which might be gained in the soil profile once the water enters the saturated zone, sophisticated drainage systems may also be required.

# SECTION II

# RECOMMENDATIONS

It is recommended that the models should be further developed and field tested to arrive at a practical model which can serve as a tool for irrigation management with the objective of return flow quality control. The field testing should include the water table depth and irrigation water quality as variables. It is recommended that this work first be continued on the Hullinger farm. Later it will be necessary to test the models against data from other locations having different field conditions including different crops, soils, climate, etc.

Initial efforts to improve the simplified model should be concentrated on adequately estimating the movement of water since water is the transporting medium for the salt. Of primary concern is the incapability of the model to account for upward flow of water from the saturated zone. Redistribution of moisture should also be considered to compensate for variation in moisture extraction from different soil layers and for situations when insufficient irrigation water is applied to bring all layers to the upper limit of field moisture. Once the water flow has been accurately described, there is hope for predicting salt movement, whether an empirical method is used or whether an attempt is made to describe in detail the chemical processes involved.

The simplified model predictions of salt movement were shown to be significantly greater than indicated by the field measurements. This implies that the leaching factor function did not provide an adequate means of simulating salt movement. Sources of error could be the method of laboratory measurement or the development of the leaching factor function from laboratory data. Rate of application of water to the disturbed soil columns in the laboratory ranged from 1.1 to 2.3 inches per hour, as compared with the irrigation application rate on the field experimental plots of 0.25 inches per hour. The development of the leaching factor function included extrapolation to regions of much higher initial moisture contents than were studied in the laboratory. Only initial volumetric moisture contents of 0.05, 0.15, and 0.20 were used in the laboratory to arrive at leaching factors for various effluent ratios. Measured field moisture contents used as initial conditions to test the model were often between 0.30 and 0.40.

It is recommended that other approaches to obtaining the leaching factor function be studied. One approach might be to use field measurements of the electrical conductivity of the soil solution ($EC_s$) to indicate areas where undisturbed soil samples might be taken. The undisturbed samples could be used in place of the disturbed soil columns to determine the leaching factor. The $EC_s$ of the samples could cover the range that would be expected in the field. When calibrating the soil, initial moisture content and all other conditions should be as close as possible to conditions in the area to which the model is to be applied. Another approach may be to make use of the detailed model (requiring large amounts of information as input) to determine a leaching factor function. Although the detailed model itself may be of limited value fron a management standpoint, because of excessive amount of computer time required, it might serve to calibrate the soil in an area of interest. The simplified model could then be used to schedule irrigation according to predicted salt and water conditions.

The detailed model provides a basic framework for solving problems that involve water quality and quantity in irrigation return flow, since salt movement in the soil depends primarily on water movement. Moreover, development of the model provides a basic step in irrigation water management, as to how much and when to irrigate.

Some of the weaknesses of this model are that it did not consider hysteresis or layered soil although both of these have been considered earlier. Further assumptions were that the soil properties did not change with time. Moreover, this model requires some assumption regarding the partitioning of potential evapotranspiration into potential transpiration and potential evaporation directly from the soil. At present, this partition is done rather crudely based on an estimate of percent of cover of the plant.

Therefore, further research for the development of this program should be pursued. The recommended research is: 1. Development of the program to account for the variation of soil and climate parameters with time, therefore increasing the accuracy of computed values. 2. Simplifications of the model to reduce computer time and input data needed since the accuracy of the computed values is fair enough for many practical purposes.

Since the detailed model was not tested under a variety of initial and boundary conditions for salt flow, it should be further investigated in the field and laboratory to determine its suitability. In addition, there appears to be at least five related areas where more investigation is needed to improve and test this model. They are:

1. What is the effect of "built in" dispersion in numerical methods on the salt flow?
2. How do the activity coefficients of different ionic species vary at high salt concentration in soil solutions?
3. How do the exchange coefficients behave in the mixed salt solutions at high salt concentrations?
4. What is the correction due to other complex ion formations at high salt concentrations?
5. Because it was concluded that powdered salt does not dissolve immediately after wetting under unsaturated flow conditions, it is recommended that salt solutions rather than salt crystals should be used in field studies.

The basis for using the soil profile as a salt storage reservoir is the concept that crops can tolerate higher concentrations of salt in the soil water where the roots are less dense. The effects upon plant physiology and crop yields of salt distribution in the root zone need to be more accurately defined. Results of such studies could provide reasonable concentration constraints for various parts of the root zone to be used in the models. It is probable that some situations may require the incorporation of a time dependent root development and extraction pattern into the models.

Economics of irrigation management should be studied in considerable detail recognizing benefits other than control of return flow quality.

Flow of water and salt in the saturated zone within the groundwater needs to be evaluated if valley wide salinity control is to be practical. Effects of both man-made and natural drainage must be considered. Such studies are necessary before benefits from irrigation scheduling on a district or valley wide basis can be determined. Another deficiency involves data collection under field condition. Many uncertainties in measured data made a full evaluation of the model difficult. Methods for obtaining more reliable data should be developed. More reliable methods for determining the electrical conductivity of the soil solution in the field are required. Alternatives are solution extraction or in-place salinity sensors. Extraction of a sufficiently large volume of solution was a problem in this study. Probes for field measurement of salinity tested in this study did not perform satisfactorily under field conditions.

## SECTION III

## INTRODUCTION

The recent (February, 1972) session of the Federal-State Enforcement Conference on the Colorado River held in Las Vegas, Nevada, reemphasized the problem of salinity in the Colorado River Basin. The considerations of the session were based mainly upon a report by Regions VIII and IX of the United States Environmental Protection Agency (1971) entitled "The Mineral Quality Problem in the Colorado River Basin." Included in the conclusions of the report are the following:

1. Salinity (total dissolved solids) is the most serious water quality problem in the Colorado River Basin.
2. Salinity concentrations in the Colorado River system are affected by two basic processes:
    - (a) salt loading, the addition of mineral salts from various natural and man-made sources; and
    - (b) salt concentrating, the loss of water from the system through evaporation, transpiration, and out-of-Basin export.
3. Salinity control in the Colorado River Basin may be accomplished by the alternatives of:
    - (a) augmentation of Basin water supply;
    - (b) reduction of salt loads (including improvement of irrigation and drainage practices);
    - (c) limitation of further depletion of Basin water supply.

This report deals with the possibility for controlling the quality of irrigation return flow by proper management of the application of irrigation water. Such management depends upon knowledge of water and salt movement through the root zone of the crops. Return flow of water to streams from irrigation water applied to fields is profoundly influenced by the soil through which it flows. There is, first of all a very large decrease in the amount of the irrigation water appearing as return flow because of return to the atmosphere as a vapor during the evapotranspiration process. Decrease in water may be complete but commonly ranges from 90 to about 50 percent of the irrigation applied. Since soluble salts are mostly excluded from plant uptake and are left behind in the soil during evaporation, there is a concentrating effect of the salts in the solution drained from a soil compared to the solution concentration entering. The water draining from the soils may be so high in salts that its further use is severely limited--a serious problem in the Colorado River Basin. In addition, the natural weathering of soils with precipitation, solution and exchange of constituents in the soil solution with the solid soil particles further influences the concentration of the soil solution. Further complicating the picture is the time delay, amounting to storage, in movement of constituents in the soil water from one part of the soil to another.

Irrigation return flow quality is affected in many segments of the water's path from diversion until its return to the stream, lake, or groundwater. This report considers the possibility for influencing return flow quality within the root zone of crops. The other segments of the water path were not included in the study. All segments would need to be considered to assess the full impact of any proposed control measure.

## Objectives

Before it is possible to develop rational management procedures, taking into account the quality of the irrigation return flow, it is necessary to be able to describe the major aspects of the system. It was the purpose of this research to develop and field test rational models for predicting the salt and water status within the soil between the time of entry as irrigation water and the time of departure as drainage water, or evaporation from the soil, or transpiration by the plant.

Specifically the objectives were:

1. To develop a model to be used as a tool for irrigation management encompassing the factors having a significant effect on the quality of irrigation return flow.
2. To develop a model for prediction of the simultaneous flow of salt and water in a soil subject to irrigation. For purposes of implementation the objective was broken down into two parts:
   (a) to develop and field test a model for estimating soil water flow subject to natural precipitation, irrigation, root extraction and transpiration by plants, evaporation of water directly from the soil and drainage;
   (b) to develop and field test a model for predicting salt distribution in the soil and drainage water under irrigated field conditions.

## Organization of Research

The research to meet the stated objectives was conducted in several parts. The model development proceeded with a two-pronged approach resulting in the "simplified" and "detailed" models explained in the report. The simplified model was intended to provide a tool for irrigation management. It was formulated to require a small amount of computer time and a minimum of field data as input and to allow consideration of a wide range of variation of factors affecting the quality of irrigation return flow. It was expected that the model would predict gross effects rather than detailed ones. On the other hand, the main purpose of the detailed model was to understand the specifics of simultaneous water and salt flow through the crop root zones. The detailed model was based more closely on known physical principles and laws governing water movement through partially saturated soils.

Both models were tested against data measured in the field during the irrigation season. The field data were collected on the Hullinger farm near Vernal, Utah. About 35 acres of the farm were operated specifically for the quality of irrigation return flow studies.

Laboratory work was needed to test some modeling concepts as well as to analyze the samples taken in the field. Examples of laboratory studies were the determination of the leaching factor function for the simplified model and the soil characteristics for the detailed model. It was necessary to conduct laboratory column studies to aid in evaluation of salt movement description capabilities of the detailed model.

# SECTION IV

## REVIEW OF LITERATURE

A current approach to the field soil water cycle is based on recognition that the field and all its components--soil, plant, and atmosphere taken together--form a physically unified and dynamic system (Gardner, 1960; Cowan, 1965) in which various flow processes occur sequentially like links in a chain. This unified system has been called "SPAC" (for "soil-plant-atmosphere-continuum") by J. R. Philip (1966). In this system, flow takes place from higher to lower potential, with the concept "water potential" equally valid and applicable in soil, plant, and atmosphere alike.

To characterize the SPAC physically, therefore, it is necessary to evaluate the potential of water and its change with distance and time along the entire path of water movement (Hillel, 1971). The flow rate is everywhere inversely proportional to an appropriate resistance. The flow path includes the water movement in the soil toward the roots, absorption into the roots, transport in the roots to the stems through the xylem to the leaves, evaporation in the intercellular air spaces of the leaves, vapor-diffusion through the stomatal cavities and openings to the quiescent air layer in contact with the leaf surface and through it to the turbulent boundary layer, whence the vapor is finally transported to the external atmosphere.

Soil water flow to plant root has been studied by a number of investigators. The studies of Philip (1957), Gardner (1960), and Molz et al. (1968) consider the radial flow of water to a single root. However, other studies (Ogata, Richards, and Gardner, 1960; Gardner, 1964; Whistler, Klute, and Millington, 1968; Molz and Remson, 1970, 1971; and Molz, 1971) deal with the removal of moisture by the root zone as a whole without considering explicitly the effects of individual roots. For convenience, the term "microscopic" is used for the flow process in the vicinity of a single root, and "macroscopic" for the overall moisture extraction process in an entire root zone.

### Models for Root Extraction

Soil water potential decreases as soil water content decreases. The soil will deliver water to the root as long as the water potential in the root is maintained less than in the soil. However, as a root extracts water from the soil in contact with it, the water potential in the soil

Preceding page blank

contact zone may decrease, as well as the hydraulic conductivity. Water uptake may decrease, assuming the root water potential stays constant, unless additional water can move in from the farther reaches of the soil in direct contact with the root. In order for this additional water to become available to the plant, not only must the soil water potential be greater than the root water potential, but the hydraulic conductivity of the soil must be large enough so that water will move toward and into the root at a rate sufficient to compensate the plant for its own loss of water to the atmosphere by transpiration.

These principles have been applied on both a microscopic and macroscopic scale. These two approaches will now be discussed in detail.

## Microscopic Approach or Single Root Model

In this approach the details of the flow about a single root are examined. On the assumption that a typical root can be represented by an infinitely long, narrow cylinder of constant radius and water-absorbing characteristic (effectively a line sink), and that soil water movement toward the root is radial, the appropriate form of the flow equation is:

$$\frac{\partial \theta}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left( rD\frac{\partial \theta}{\partial r} \right) \qquad [1]$$

where $\theta$ is volumetric soil water content, D is diffusivity, t is time, and r is radial distance from the axis of the root. Assuming constant flux at the surface, Gardner (1960) solved this equation subject to the following initial and boundary conditions:

$$\theta = \theta_0 \qquad h = h_0 \qquad t = 0$$

$$q = 2\pi aK\frac{\partial h}{\partial r} = 2\pi aD\frac{\partial \theta}{\partial r} \qquad r = a, \qquad t > 0 \qquad [2]$$

where a is the root radius, h is matric potential, K is hydraulic conductivity, and q is the rate of water uptake by the root or the flux of water at the root surface expressed as volume of water per unit length of root per unit time. The solution of Equation [1] subject to Equation [2] for constant D and K and sufficiently long time is:

$$h - h_0 = \Delta h = \frac{q}{4\pi K}\left[\ln\left(\frac{4Dt}{r^2}\right) - \gamma\right] \qquad [3]$$

where $\gamma$ is Euler's constant = 0.57722 . . . . From this equation, it is possible to calculate the gradient $\Delta h$ that will develop at any time between the soil at a distance (r - a) from the root (i.e., the initial soil water potential $h_0$) and the matric potential h at the root-to-soil contact zone. Since diffusivity, time, and radius at the root occur in a logarithmic term in Equation [3], $\Delta h$ is much less sensitive to these three factors than to q and K. Gardner (1960) showed that a ten thousandfold variation in D would cause only about a ninefold variation in $\Delta h$, hence the assumption of an average constant value of D does not introduce a serious error. Similarly, Gardner showed that root size is not extremely important; the root diameter should be important only when resistance to water entry in the root is large compared with resistance to water movement in the soil. This is probably the case only in wet soils. Moreover, the variation in K, due to $\Delta h$, was considered to be no larger than the uncertainties in determination of K, so that the assumption of a constant K was valid for not too large K. Equation [3] shows that the gradient $\Delta h$, or the increase of soil water potential above the initial value, is directly proportional to the rate of water uptake and inversely proportional to the hydraulic conductivity of the soil. The root water potential can, therefore, be expected to depend on these two factors as well as on the average soil water potential. Hence, when soil water potential is high and conductivity high, $\Delta h$ is small and the potential in the root will not differ markedly from the potential in the soil. When soil water potential decreases and soil hydraulic conductivity decreases, the potential difference (or gradient) needed to maintain the same flow rate must increase correspondingly. As long as the transpiration of the plant is not too high, and as long as the hydraulic conductivity of the soil is adequate and the density of the roots is sufficient, the plant can extract water from the soil at the rate needed to maintain normal activity. However, the moment the rate of extraction drops below the rate of transpiration (either because of high evaporative demand by the atmosphere, and/or because of low soil conductivity, and/or because the root system is too sparse), the plant necessarily loses water, and if it cannot adjust its root water potential or its root density so as to increase the rate of soil water uptake, the plant may suffer from loss of turgor. This situation will sooner or later cause the plant to wilt.

## Limitations of the Microscopic Approach

The limitations of the microscopic approach are:

1. The diffusivity, D, and hydraulic conductivity, K, of the soil were assumed constant (Gardner, 1960), while they change as soil water and salt concentration change with time and depth.
2. The model has been based on the assumption that the roots are uniformly distributed in the rooting zone, and that the average soil water potential is similarly uniform within the rooting zone (Gardner, 1960; Molz et al., 1968). In actual fact, root systems in the field are seldom, if ever, uniform with depth.
3. Another limitation of the microscopic approach is the determination of the correct boundary condition at the root surface. Most authors have used either a constant flux condition (Gardner, 1960) or a constant head condition (Molz et al., 1968). The correct condition would probably be some combination of both that varied temporally (Molz and Remson, 1970). Moreover, if an attempt is made to treat realistically more than one root at a time, it becomes very difficult to specify the geometry correctly. An added difficulty is measuring the necessary variables with macroscopic instruments.

Based on the microscopic approach, the usual method for studying the composite soil-plant system has been to consider flow to a single "typical root." The results are then multiplied by an "average" root density to obtain generalizations concerning the entire root-plant system (Gardner, 1960; Cowan, 1965).

## Macroscopic Approach or Bulk Root Model

In this model the flow to individual roots is ignored and the overall root system is assumed to extract moisture from each differential volume of the root zone at some rate. At a given point, this rate can depend on position in a coordinate system, water content, soil conductivity, time, etc. The water-removing roots may then be represented as an extraction (sink) term in the soil water flow equation.

Ogata, Richards, and Gardner (1960); Gardner (1964); Whistler et al. (1968); Molz and Remson (1970, 1971); and Molz (1971) have considered the macroscopic approach. Gardner (1964) modified Equation [3] from a single root system to an entire root system:

$$W = (h_{plant} - h_{soil})/R \qquad [4]$$

where W is the rate of water uptake per unit volume of soil, $h_{plant}$ is water potential within the plant root, $h_{soil}$ is the total water potential in the soil, and R is the resistance to water movement in the soil, $R_s$, and the plant, $R_p$. In specifying R, one can assume that the soil and the plant resistance can be added in series so that $R = R_p + R_s$. Gardner and Ehlig (1962) suggested that $R_p$ may be small compared to $R_s$; therefore, it is assumed to be negligible. According to this, Gardner (1964) assumed that the water potential is uniform throughout the entire root system at any one time. On the other hand, Molz and Remson (1970) devised an extraction term that depended only on depth and transpiration rate. They used an empirical rule, given by Danielson (1967) that 40 percent, 30 percent, 20 percent, and 10 percent of the total transpiration requirements comes from each successively deeper quarter of the root zone. Molz and Remson (1970) considered these numbers 40, 30, 20, and 10 of no special significance but they regarded them as "reasonable" quantities to write their root extraction term:

$$S(z) = -\frac{1.6Tz}{v^2} + \frac{1.8T}{v} \qquad 0 \leq z \leq v \qquad [5]$$

where S(z) is the water extraction rate per unit volume of soil, z is the vertical distance positive downward, v is the vertical length of the root system, T is the transpiration rate per unit area of soil surface. In some cases, T is interpreted as an "average" transpiration rate.

The total water extraction rate from a volume of soil of unit cross section bounded by the horizontal planes $z = z_1$ and $z = z_2$ where $z_1 < z_2$ is:

$$\int_{z_1}^{z_2} S(z)dz \qquad [6]$$

Because the extraction rate from the root zone equals the transpiration rate, then:

$$T = \int_0^v S(z)dz = -\frac{1.6T}{v^2}\frac{z^2}{2}\Big|_0^v + \frac{1.8Tz}{v}\Big|_0^v \qquad [7]$$

It can be verified that Equation [5] meets the stated percentage requirements by integrating over the appropriate portions of the root zone. To account for root systems that are growing so that $v = v(t)$, Molz and Remson (1970) generalized Equation [5] to:

$$S(z, t) = -\frac{1.6Tz}{(v(t))^2} + \frac{1.8T}{v(t)} \qquad [8]$$

Combining Equation [8] with the general flow equation in one dimension, and assuming steady state conditions, they obtained the partial differential equation:

$$0 = \frac{\partial}{\partial z}\left(D\frac{\partial\theta}{\partial z}\right) - \frac{\partial K}{\partial z} - (az - b) \qquad [9]$$

where D is diffusivity, $D = K\,\partial h/\partial\theta$, h is matric potential, $\theta$ is volumetric water content, $a = -1.6T/v^2$, and $b = 1.8T/v$. Equation [9] was applied to the data from an experiment of Gardner and Ehlig (1962) and yielded reasonable results.

## Limitations of the Macroscopic Approach

The macroscopic approach has been studied under controlled experiments, but it has not been widely used and knowledge of its utility and behavior is limited under field conditions. Other limitations of the macroscopic models that have been studied are:

1. A uniform root distribution and water potential were assumed throughout the root system at any one time (Gardner, 1964). These assumptions rarely exist under field conditions. It was also assumed that the plant resistance to water movement was negligible compared to the soil resistance to water movement (Gardner, 1964), but roots are not uniformly permeable to moisture (Slayter, 1960).

2. Steady state was assumed to solve the model (Whistler, Klute and Millington, 1968; Molz and Remson, 1970). Steady state rarely occurs in the field.

3. A constant "average" transpiration rate and an initial uniform moisture content of approximately field capacity were used to solve the macroscopic model by Molz and Remson (1970 and 1971) and Molz (1971) utilizing controlled column experimental data collected by Gardner and Ehlig (1962) and Gardner (1964).

Moreover, extraction models such as Equations [5] and [8] may give reasonable qualitative results for higher moisture contents, but it is doubtful if they will agree in detail with experimental results. One reason for this is that as the upper layers of soil dry, more of the transpiration requirements comes from deeper roots in the wetter soil (van Bavel, Stirk, and Brust, 1968). This is not accounted for in Equations [5] and [8]. However, for a steady state, the moisture extraction pattern is static and models such as Equations [8] and [9] can yield reasonable results (Molz and Remson, 1970).

The macroscopic approach has significant advantages over the microscopic approach. The geometry for a one-dimensional model is quite simple. The boundary conditions are easy to identify and apply compared with those that occur at the root surface in the microscopic treatment. The upper boundary conditions are usually taken at the soil surface; thus evaporation, rainfall, or zero flow conditions can be accounted for. The lower boundary might be an impermeable layer or water table. Moreover, any results obtained from the macroscopic model apply directly to the SPAC as a whole.

## Column Chromatography

Most of the models developed for tracing salt distribution in soils are based on the laws of conservation of mass. They state that the amount of salt added by water applied to the soil layers, minus the amount leached out and the amount absorbed by plants is equal to the net increment (positive or negative) of salts in the soil layer.

Any attempt to gather information on the vertical transport of different ions or salt solutions through the soil results in a mass of chromatographic theories. Two different approaches can be defined in the literature. The first one is based on the kinetic process called the "rate theory" (DeVault, 1943; Hiester and Vermeulen, 1952; and Lapidus and Amundson, 1952). The second one is the plate theory of Glueckauf (1949), Thornthwaite, Mather, and Nakamura (1960), Dutt et al. (1971), and Bresler (1967) in which the height of a plate in the column is the unit of calculation. Historical development of the two different schools of thought will be reviewed separately in the following sections.

## Rate Theory

One of the simplest rate theories is that of DeVault (1943). It is also described as the equilibrium chromatography. It requires that the penetrating solution move through the porous medium at such a rate that a dynamic equilibrium between the ions in solution and adsorbed phase shall be maintained. The theory starts with a material balance over a cross sectional layer of the column of thickness dz:

$$\frac{\partial c}{\partial z} + \alpha \frac{\partial c}{\partial v} + \frac{\partial E}{\partial v} = 0 \qquad [10]$$

where c is the concentration of solute in the solution phase, E is the concentration of solute in the solid phase, z is the distance from the top of the column, $\alpha$ is the pore or void fraction of the column and v is the volume of the solution fed to the column. Under saturated flow the general solution of this equation is

$$z = g(c) + \frac{v}{\alpha + \phi f'(c)} \qquad [11]$$

where $\phi$ is the amount of adsorber per unit of length, $f'(c)$ is the derivative of f(c) with respect to c, f (c) is the adsorption isotherm defined in such a way the $E = \phi f(c)$ and g(c) is any function determined by the initial distribution of solute through the column.

Rible and Davis (1955) applied this theory with some success to predict ion distribution in soils. The theory is less involved mathematically but is limited in application to soil because of the assumption of instantaneous equilibrium and negligible channeling.

Hiester and Vermeulen (1952) started with another material balance equation:

$$-\left(\frac{\partial c}{\partial u}\right)_v = \left(\frac{\partial E}{\partial v}\right)_u + \alpha\left(\frac{\partial c}{\partial v}\right)_u \qquad [12]$$

where u is the bulk packed volume of the column ($u\alpha$ = void volume) up to point z. Their work was the extension of work started by Thomas (1944) who took account of the rate of exchange by second order kinetics. The starting point is

$$A^+ + BX \rightarrow B^+ + AX \qquad [13]$$

and the rate equation being

$$\frac{\partial E}{\partial t} = k\ [c(E_T - E) - \frac{E}{K}(c_o - c)] \qquad [14]$$

where $A^+$, $B^+$ are cations and X is the exchanger, $E_T$ is cation exchange capacity, $c_o$ is the total cation concentration in solution, k is the specific rate factor, and K is the equilibrium constant. They further defined dimensionless parameters, solution capacity parameter T, column capacity parameter s, and equilibrium parameter r, to reduce Equation [12] to

$$-\left[\frac{\partial(E/E_T)}{\partial T}\right]_s = \left[\frac{\partial(c/c_o)}{\partial s}\right]_T \qquad [15]$$

and Equation [14]

$$\left[\frac{\partial(E/E_T)}{\partial T}\right]_s = \left[\frac{c}{c_o}\left(1 - \frac{E}{E_T}\right) - r\,\frac{F}{E_T}\left(1 - \frac{c}{c_o}\right)\right] \qquad [16]$$

Hiester and Vermeulen (1952) have provided the graphical and numerical solution to Equations [15] and [16] in terms of parameters T, s, and r.

Bower, Gardner, and Goertzen (1957) tested this theory in the soil system. They found a reasonably good agreement between the theoretical and experimental values for the distribution of dissolved and exchangeable ions in the soil column as a function of depth and volume of solution applied. Gardner and Brooks (1957) distinguished between immobile and mobile salt moving with the same velocity as the leaching front. They adopted and tested the theory of Hiester and Vermeulen (1952) in laboratory column and field plots of Pachappa sandy loam. Agreement between the predicted and experimental values was found to be satisfactory.

The model of Hiester and Vermeulen differs from the proceeding model of DeVault in that rate dependent processes are considered in lieu of the assumption of equilibrium. However, both the models ignore the dispersion of salts.

The third model that is based on kinetics is by Lapidus and Amundson (1952). They have developed a model which takes into account the dispersion in addition to the mass flow. Previous work of Nielsen and Biggar (1962) has shown this model as the most satisfactory of all models investigated for predicting the spreading of a non-interacting solute, in porous media, where spreading results from diffusion and dispersion. When exchange is also considered the material balance over a layer dz is,

$$D \frac{\partial^2 c}{\partial z^2} = \bar{v} \frac{\partial c}{\partial z} + \frac{\partial c}{\partial t} + \frac{1}{\alpha} \frac{\partial E}{\partial t} \qquad [17]$$

where D is the dispersion coefficient. Depending upon the boundary conditions, the equation can be solved analytically (Nielsen and Biggar, 1962) or numerically (Lai, 1970). Some of the assumptions implied in the above model are that the velocity profile can be represented by an average $\bar{v}$, the diffusion coefficient is constant, equilibrium between the two phases is established and there exists some relationship between the ions in solution and the exchanger. A comparative study of three models, DeVault (1943), Hiester and Vermeulen (1952), and Lapidus and Amundson (1952) was reported by Biggar and Nielsen (1963) using Oakley sand. They concluded that all the theories were generally inadequate to describe the experimental values. The lack of agreement was attributed to the inadequate description of exchange, the use of the average value of the flow velocity and the diffusion coefficient.

### Plate Theory

In the plate theories the column is regarded as being divided into a large number of segments or plates. Within each plate the concentration is considered to be uniform both in sorbent and liquid phases, the two concentrations being assumed to be at equilibrium. It is immaterial whether an exchange process, diffusion process, or any other process is envisaged as the main dispersion process. It is also implied that there is only one unit of length to which this definition applies. If the height of the plate is too long, the concentration may not be regarded as uniform and if it is too short no equilibrium is possible between the two concentrations.

One of the plate theories that has been extensively tested in the soil system is that of Glueckauf (1949). The starting equation is,

$$\left(\frac{\partial f(c)}{\partial v}\right)_z + \left(\frac{\partial c}{\partial z}\right)_v - \frac{\Delta}{2}\left(\frac{\partial^2 c}{\partial z^2}\right)_v = 0 \qquad [18]$$

where $\Delta$ is the plate height. In 1956, van der Molen applied this theory to the desalinization of soils under the influence of Dutch climate (mean annual precipitation about 70 cm). The solution of Equation [18] for a homogeneous saline profile at large values of N and in the case of a linear adsorption isotherm, may be represented by

$$c = \frac{c_o}{2} \operatorname{erfc} \frac{p - 1}{\sqrt{2p}} \sqrt{N} \qquad [19]$$

where N is the number of depths above a distance z, $p = v/\alpha\rho d$,

$\operatorname{erfc} n = 1 - \frac{2}{\pi}\int_0^n e^{-u^2} du$, $\rho$ is the density of the soil, and d is the distance from the soil surface. Some general agreement was found in theoretical and observed values. Dyer (1965) studied the distribution of chloride and nitrate ions in adjacent irrigated and non-irrigated areas and observed a close fit of theoretical values with the observed ones.

Finally, there are two other very practical theories that have nevertheless retained the characteristics of chromatographic transport. Both the theories consider the fixed plate height. Thornthwaite et al. (1960) and Frissel and Poelstra (1964) have described the transport of strontium through soils. Their method is based on Martin and Synge (1941) theory except that the plate height is fixed and it is assumed that 0.1 part of Sr in each layer is leached downward to the next layer, for every unit of the leaching solution added to the soil. If at the beginning of leaching only one layer is loaded, the concentration in the nth layer $c_n$ is found from

$$c_n = \frac{t'!(0.1)^{n-1}(0.9)^{t'-n+1} c_o}{(t'-n+1)!(n-1)!} \quad [20]$$

where $c_o$ is the total concentration in the first layer and t' is the number of leaching cycles.

The other approach which has received widespread attention is by Dutt (1963) and his co-workers. He has used a method for calculating the quality of water percolating through soil containing gypsum. The concentration of salts at any depth and time is given by

$$c_i^j = c_{i-1}^j \left( \frac{\theta S_i - \theta_i^o}{\theta S_i} \right) + c_i^{j-1} \left( \frac{\theta_i^o}{\theta S_i} \right) \quad [21]$$

where i and j are depth and time, respectively. $\theta$ is the moisture content and $\theta S_i$ is pore volume at any depth. $c_i^j$ is then corrected for solubility of minerals and exchange with the soil.

The advantage of this type of approach is that it is possible to introduce such factors as solubility of minerals, etc. Since exchange constants are used it means no linear adsorption isotherm is necessary. The main drawbacks of Dutt's (1963) model are that the process is discontinuous and unknown dispersion is present even when physical dispersion is ignored in the model.

Review of the different models applied to the soil for describing the movement of salt are discussed by Frissel et al. (1967) and Biggar and Nielsen (1963). For the most part previous investigators have used constant flow velocities. A notable exception is the work of Bresler and Hanks (1969) who describe the numerical technique for simultaneous flow of water and salt in unsaturated soils and allow for time dependent velocities. This work was essentially a combination of Bresler's (1967) model for salt flow, and Hanks and Bower's (1962) model for water flow. The model starts with a material balance equation

$$\left[\frac{\partial(\theta c)}{\partial t}\right]_z = \left[\frac{\partial}{\partial z}\left(\theta D\frac{\partial c}{\partial z}\right) - \frac{\partial(\bar{v}c)}{\partial z} + S\right]_z \qquad [22]$$

where $\bar{v}$ is the volumetric flux of water given by Darcy's law, t is the time, S is the sink or source term due to the solubility of mineral or exchange between solid and solution phase. Equation [22] is similar to the equation given by Lapidus and Amundson (1952). The present model of Bresler and Hanks (1969) contains the important features of rate as well as plate theory. The plate height is variable with depth but is constant with time. The model ignored the dispersion and sink or source term. However, a critical examination of the numerical method indicates a tendency for the concentration profile to spread for noninteracting salts rather than have a sharp profile, thus indicating a "built in" dispersion in numerical approximation like Dutt (1963). The model has been tested in the laboratory and gave values which agreed well with the experimental results.

## SECTION V

## DEVELOPMENT OF MODELS

A very important aspect of water quality in rivers of arid regions is salinity (total dissolved solids). Since irrigation return flow constitutes a large part of the influent to such rivers, control of the salinity of irrigation return flow is vital to any program of salinity control in a river basin. Irrigation practices can greatly affect the quality of irrigation return flow. Proper management of the application of irrigation water depends upon knowledge of water and salt movement through the root zone of the crops. Two different models were developed for describing flow of water and salt through the soil with extraction of water by evapotranspiration. The two are called "simplified" and "detailed" models for the purposes of this report. The development of each model is outlined in the following.

### Simplified Model

The simplified model was developed to serve as a tool for irrigation management. It was formulated to require a small amount of computer time and a minimum of field data as input and to allow consideration of a wide range of factors affecting the quality of irrigation return flow. The simplified model was designed to predict gross effects rather than detailed ones.

Two separate versions of the simplified model were developed. The two are called "prediction" and "evaluation" versions according to the general philosophy of their use. The evaluation version uses a predetermined irrigation schedule, specifying the timing, depth and quality of water applied for each irrigation, to determine the effects of the schedule upon quality and quantity of water entering the saturated zone and upon the salinity status within the unsaturated soil profile. The prediction version differs in that it determines the proper depth of water to be applied in each irrigation so that the concentration of salts in the soil moisture does not exceed a preset value. The details of the prediction version of the simplified model will be given first.

#### Prediction Version

The prediction version of the simplified model is based upon the concept of temporarily storing salt in the soil profile and leaching only when

**Preceding page blank**

necessary to prevent the salt from becoming too concentrated in the soil moisture. The unsaturated zone is divided into "n" layers of equal thickness. A constraint is set on the allowable concentration in each layer. The calculation begins by adding to the top layer sufficient water to fill the available soil water reservoir for the entire unsaturated zone. The computer program calculates the movement of water and salt from layer to layer through the profile. If the concentration constraint of any layer is exceeded, then the computer program iterates by adding more water until the constraint is satisfied. After the proper depth of water to be applied in a given irrigation has been determined, the final conditions existing in the profile (after passing of the time interval between irrigations) become the initial conditions for the next irrigation. Thus, the entire irrigation season is covered in one computer run.

The crop is assumed to extract pure water leaving the salt behind in the soil moisture. The water and salt are assumed to move downward through the soil — lateral and upward movement are not allowed. The model uses an "upper limit of field moisture" concept i. e., after an irrigation, downward drainage of water occurs until the soil reaches the upper limit of field moisture, after which all downward movement of water ceases. The upper limit of field moisture must be determined for each soil layer under conditions to be encountered in the field. For layers near and including the water table, the upper limit will be the saturated moisture content.

Figure 1 shows a typical layer of soil with the symbols as follows:

DX is the thickness of the layer.

ET is the total depth of water extracted from the layer by evapotranspiration.

$d_e$ is the depth of water entering the layer.

$\theta_o$ is the initial volumetric moisture content of the layer.

$\theta_{fm}$ is the volumetric moisture content when the soil contains the upper limit of field moisture.

$\theta_f$ is the final volumetric moisture content existing in the layer at the end of the irrigation interval.

$d_1$ is the depth of water leaving the layer.

$C_e$, $C_o$, $C_{fm}$, $C_f$, and $C_1$, denote the corresponding concentration of salt in the water.

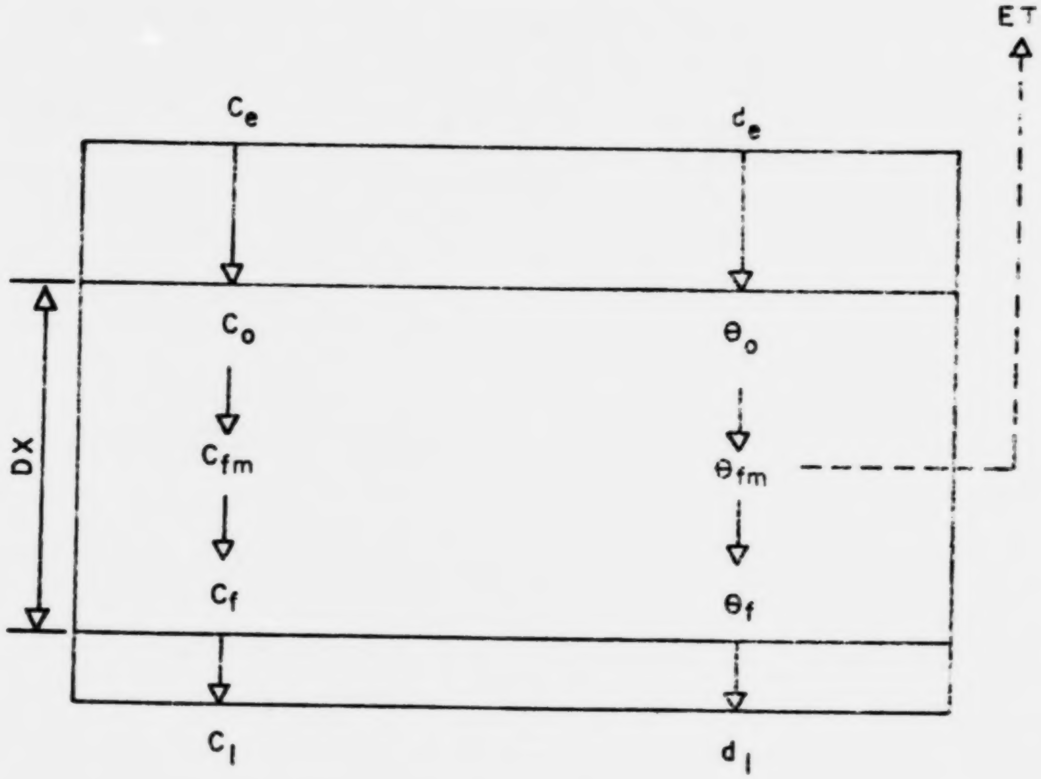
ET
C_e
d_e
DX
C_o
θ_o
C_fm
θ_fm
C_f
θ_f
C_l
d_l

Figure 1. Typical layer of soil in simplified model.

The movement of water is treated in a fairly simple manner. Since drainage from a particular layer ceases when the soil reaches the upper limit of field moisture, the depth of water leaving the layer is equal to the depth entering minus the depth required to bring the soil layer to the upper limit. Thus, in equation form

$$d_1 = d_e - DX(\theta_{fm} - \theta_o) \qquad [23]$$

After the soil layer reaches the upper limit of field moisture, the only loss of water from the layer is by evapotranspiration. This version of the model assumes that the minimum amount of water applied is that required to bring each soil layer to the upper limit of the field moisture. Thus, the final moisture content of the layer is determined from the difference between the amount of water at the upper limit and the amount extracted by evapotranspiration for the period between irrigations. In equation form, the final moisture content is given by

$$\theta_f = \theta_{fm} - ET/DX \qquad [24]$$

The movement of salt is more difficult to describe. A mass balance on salt of any layer can be written as

$$C_e d_e + C_o d_o = C_1 d_1 + C_{fm} d_{fm} \qquad [25]$$

in which $d_o$ and $d_{fm}$ are depth of water corresponding to $\theta_o$ and $\theta_{fm}$, respectively, i.e., $d_o = DX\,\theta_o$ and $d_{fm} = DX\,\theta_{fm}$. Since it is assumed that evapotranspiration removes salt-free water from the layer, the mass of salt in the layer does not change as the moisture content is reduced from $\theta_{fm}$ to $\theta_f$; however, the salt becomes more concentrated in the water remaining in the layer ($C_f > C_{fm}$). In other words $C_{fm} d_{fm} = C_f d_f$ and Equation [25] can be written

$$C_e d_e + C_o d_o = C_1 d_1 + C_f d_f \qquad [26]$$

All terms in Equation [26], except $C_1$ and $C_f$, are known or can be determined. The final concentration, $C_f$, is not allowed to become greater than a certain value (concentration constraint) and can be solved for only if $C_1$ is known.

Using soil samples from the field, a laboratory method of calibrating the soil to estimate $C_1$ was developed (Rasheed, 1970; Titavunno, 1971). Details of this calibration are given later in this report in the section entitled "Testing of Models". This calibration technique was based upon a leaching factor, LF, defined as

$$LF = C_1 d_1 / (C_o d_o + C_e d_e) \qquad [27]$$

It was concluded from the laboratory data (See Table 1) that the measured leaching factor could be described as a function of $d_1$ and $\theta_o$. From the measured leaching factor and Equation [27], $C_1$ can be determined and from Equation [26], $C_f$ can then be found. The leaching factor function is contained in a subroutine, thus only the subroutine needs changing to model a different field soil.

A FORTRAN listing of the computer program is given in Appendix A. A step-by-step description of the computer program for the prediction version of the simplified model follows:

1. The input data are read. These data include the number of separate problems to be solved in the particular computer run, a print control integer, the number of soil layers, the length of season in days, the number of days between irrigations, the number of days from the soil sampling to the first irrigation, the thickness of each soil layer, the electrical conductivity (EC) of the irrigation water, an iteration limit, the initial volumetric moisture content for each layer, the initial EC of the soil moisture in each layer, the root extraction pattern, the upper limit of field moisture for each layer, the lower limit of field moisture (wilting percentage) for each layer, the allowable upper limit of the EC of the soil moisture (concentration constraint) for each layer, and the evapotranspiration (ET) for each day of the season.
2. The total ET for the season is calculated.

Table 1. Summary of results from laboratory technique of soil calibration to determine leaching factor (LF) for Hullinger farm soil.

| Effluent Ratio (ER) | Leaching Factor (LF) | | |
|---|---|---|---|
| | $\theta_o = 0.05$ | $\theta_o = 0.15$ | $\theta_o = 0.20$ |
| 0.1 | 0.201 | 0.118 | 0.084 |
| 0.2 | 0.275 | 0.192 | 0.143 |
| 0.3 | 0.303 | 0.261 | 0.195 |
| 0.4 | 0.365 | 0.312 | 0.272 |
| 0.5 | 0.412 | 0.359 | 0.303 |
| 0.6 | 0.432 | 0.393 | 0.353 |
| 0.7 | 0.461 | 0.441 | 0.394 |
| 0.8 | 0.495 | 0.461 | 0.422 |
| 0.9 | 0.520 | 0.485 | 0.462 |
| 1.0 | 0.541 | 0.519 | 0.483 |
| 1.25 | 0.586 | 0.572 | 0.553 |
| 1.50 | 0.633 | 0.621 | 0.606 |
| 1.75 | 0.681 | 0.662 | 0.652 |
| 2.00 | 0.719 | 0.702 | 0.681 |
| 2.25 | 0.741 | 0.733 | 0.713 |
| 2.50 | 0.763 | 0.757 | 0.735 |
| 2.75 | 0.787 | 0.771 | 0.762 |
| 3.00 | 0.798 | 0.793 | 0.776 |

ER = Effluent Ratio = $d_1/d_{fm}$

3. The number of irrigation intervals is computed.

4. If time has elapsed between the field sampling (from which initial conditions were established) and the first irrigation, the moisture loss by ET in this period is accounted for and the initial conditions are adjusted accordingly.

5. At the time of the first irrigation, the depth of water necessary to fill all layers of the soil profile to the upper limit of field moisture ($\theta_{fm}$) is calculated. This depth of water is used as a first trial for the depth of water to be applied as the first irrigation.

6. The depth of water computed in Step 5 is set equal to $d_e$ for the top layer of the soil profile.

7. The depth leaving the layer is computed from Equation [23].

8. The effluent ratio ($d_1/d_{fm}$) and initial moisture content for the layer are used in the leaching factor function to obtain the leaching factor (LF).

9. The EC of the water leaving the layer is computed from Equation [27] where it is assumed that the EC is a direct measure of the concentration of salts in the water (1 mmho/cm = 640 ppm): $C_1 = LF(C_o d_o + C_e d_e)/d_1$

10. The EC at the upper limit of field capacitv ($C_{fm}$) is calculated from Equation [25], i.e.,

$$C_{fm} = (C_e d_e + C_o d_o - C_1 d_1)/d_{fm}$$

11. The volumetric moisture content at the end of the irrigation interval (immediately before the next irrigation), $\theta_f$, is calculated from Equation [24] where ET denotes the depth of water extracted from the particular soil layer by evapotranspiration during the interval of time following the irrigation.

12. The EC of the soil moisture at the end of the irrigation interval ($C_f$) is calculated from $C_f = C_{fm}\theta_{fm}/\theta_f$.

13. If $\theta_f$ is less than the wilting percentage, the problem is terminated because the interval between irrigations is too long.

14. A test is made to see if the concentration constraint for the layer is satisfied. Let the upper limit of EC (concentration constraint) be denoted as $C_t$ and the iteration limit be denoted $C_{tol}$. Then if $C_f \leq C_t + C_{tol}$, $d_1$ and $C_1$ for the layer are set equal to $d_e$ and $C_e$ for the next layer and calculation proceeds by returning to Step 7.

15. If $C_f > C_t + C_{tol}$, the trial depth of water applied (Step 5) is increased and calculations are repeated for the layer beginning with Step 7. This iteration continues until a depth of applied water is found by the method of false position (Kunz, 1957) such that $C_t - C_{tol} \leq C_f \leq C_t + C_{tol}$. Then $d_1$ and $C_1$ for the layer are set equal to $d_e$ and $C_e$ for the next layer and calculation proceeds by returning to Step 7.

16. Calculation continues until each layer of the profile successively satisfies the concentration constraint. Then conditions are re-initialized and the calculations are repeated for the next irrigation.

17. Calculations continue until all irrigations of the season have been considered.

18. When one complete problem is finished the program automatically proceeds to the next problem.

The output of the program is best illustrated by the two example problems included in the Appendix. The print control integer is used to select either a long output (Example 1, Appendix A) or a short output (Example 2, Appendix A). Both types of output include listings of all the input data. The long output includes the salt existing, the moisture content, and the EC of the soil moisture for each layer of soil immediately prior to the first irrigation and after each irrigation interval. Also given are the depth of water applied, the amount of salt leaving the soil profile, the depth of leaching water, the leaching percentage, and the ET for each irrigation interval and for the season. The short output deletes the salt existing, the moisture content, and the EC of the soil moisture for each layer after each irrigation interval.

The reader will note from the FORTRAN listing of the prediction version (Appendix A) that as now formulated, the EC of the irrigation water and the interval between irrigations are constant for the entire season.

A simple program modification would allow these quantities to vary through the season in some predetermined manner.

## Evaluation Version

The main difference between the evaluation version and the prediction version is that the depth of water to be applied for each irrigation is specified as input to the evaluation version. That is, an irrigation schedule specifying depth, timing, and EC of irrigation applications is evaluated as to its effect upon the quality of water leaving the profile and the salinity status within the profile. No constraint or limit is placed on the EC of the soil moisture and the computations do not involve iteration but are sequential from layer to layer and irrigation to irrigation. In any irrigation interval, the calculation of conditions existing in the profile on any given day is possible, and these conditions can be printed out for comparison with field measurements. The program automatically reinitializes using the calculated conditions and proceeds through the season.

In the evaluation version, there may be situations where the applied irrigation water is not enough to completely fill all layers of the soil to the upper limit of field moisture. In such cases, the water is assumed to fill each layer in succession beginning with the surface layer. When a layer is reached where the water entering from the layer above is not sufficient to fill the layer to $\theta_{fm}$, all the water is assumed to be retained in the layer; i.e., the irrigation water does not penetrate below this layer for this particular irrigation. For such a situation the final moisture content is computed from

$$\theta_f = \theta_o + d_e - ET/DX \qquad [28]$$

Also, for this layer $d_e < DX(\theta_{fm} - \theta_o)$ and the layer fills to a moisture content equal to $\theta_o + d_e/DX$ instead of $\theta_{fm}$. If $\theta_a = \theta_o + d_e/DX$ and $d_a = DX\theta_a$, then Equation [25] becomes

$$C_e d_e + C_o d_o = C_a d_a \qquad [29]$$

And since $C_a d_a = C_f d_f$, Equation [29] is equivalent to Equation [26] where $d_l = 0$. Since $d_a$ is known and $d_l = 0$, the leaching factor function is not needed for this layer and $C_a$ can be calculated directly from Equation [29].

This version of the simplified model is based upon the evaluation of an irrigation schedule in which the depth, timing, and EC of applied water are specified for each irrigation. The program is designed to allow comparison of computer results with field measurements at any day of the season. The season may be divided into a number of evaluation periods including parts of (or all of) one or more irrigation intervals and need not begin and end with the irrigation intervals. In one pass through the computer, several evaluation periods can be considered at one or more field locations.

A FORTRAN listing of the computer program for the evaluation version of the simplified model is given in Appendix A. A step-by-step description of the computer program for the evaluation version follows:

1. The input data are read. These data include the total number of evaluation periods for the computer pass, and for each evaluation period: the thickness of soil layers, a number identifying the field location, a number identifying the evaluation period, the number of irrigations in the evaluation period, the number of days from the beginning of the evaluation period to the first irrigation, the depth of water for each irrigation, the EC of the applied water for each irrigation, the length of each irrigation interval, the initial moisture content of each layer, the initial EC of the moisture in each layer, the moisture extraction pattern, the upper limit of field moisture for each layer, the lower limit of moisture (wilting percentage) of each layer, the maximum EC recommended for each layer (comparison purposes only), the ET for each day of the evaluation period. If the particular evaluation period immediately follows a period already calculated at the same location, the data of the above list from the initial moisture content to the maximum EC recommended for each layer need not be given as input but are already available internally.
2. The moisture content, EC of soil moisture, and amount of salt for each layer immediately prior to the first irrigation are calculated.
3. The depth of water required to fill the entire profile to the upper limit of field moisture is calculated.

4. The depth of water applied for the first irrigation is set equal to $d_e$ for the top layer.

5. The depth of water equivalent to the initial moisture content, $\theta_o$, and the upper limit of field moisture, $\theta_{fm}$, are computed from $d_o = DX\theta_o$ and $d_{fm} = DX\theta_{fm}$.

6. If $d_e + d_o < d_{fm}$, all the water applied is retained in this layer and $d_l = 0$. The final moisture content of the layer is computed from Equation [28] and the final EC of the layer is computed from Equation [26] (with $d_l = 0$).

7. If $d_e + d_o > d_{fm}$, the depth of water leaving the layer is calculated using Equation [23]. Then, Steps 8 through 12, inclusive, of the description of the prediction version are followed.

8. If $\theta_f$ is less than the wilting percentage, calculation proceeds but an asterisk is printed after the value of $\theta_f$. If the final EC of the layer is greater than the maximum EC recommended, an asterisk is printed after the value of EC of the layer.

9. The $d_l$ and EC of water leaving the layer are set equal to $d_e$ and EC of water entering the next layer and Steps 5 through 8 are repeated for the next layer.

10. After all layers have been considered the leaching water and amount of salt leaving the bottom layer are computed.

11. The final conditions in the profile become the initial conditions of the next irrigation interval and calculations are repeated until all irrigations of the evaluation period are completed.

12. If data for another evaluation period follow, the entire calculation procedure is repeated.

The output of the program is illustrated by an example problem (Example 3, Appendix A). First, all of the input data is printed. This example is for block 5 (field location) and has two evaluation periods. The particular period is denoted by the second number following the word "block". The value of C gives the EC of irrigation water applied, KM denotes the number of days following the irrigation (irrigation interval), and KM1 gives the number of days from the beginning of the evaluation period to the first irrigation.

## Detailed Model

The purpose of the detailed model was to understand the specifics of simultaneous water and salt flow through field soils. The detailed model was designed to determine the salt and water content within the soil and in the drainage water as a function of time and depth for saturated and unsaturated soil water flow. Since the water is the transporting medium for the salt, the development of the detailed model was handled in two parts. The first part was the development of a "water model" to describe soil water flow subject to natural precipitation, irrigation, root extraction and transpiration by plants, evaporation of water directly from the soil, and drainage. The second part was the development of a "salt model" to predict salt distribution in the soil and drainage water under irrigated field conditions. The salt model is built upon the water model as a foundation. The water model and the salt model are described separately in the following.

### Water Model

None of the previous models, discussed in the Review of Literature, have been applied to field conditions. For these reasons, and in order to encounter more variables as they exist under field conditions, a new macroscopic approach has been developed and tested under field conditions.

The bulk root model developed herein is a modification of the soil water flow model of Hanks, Klute and Bresler (1969). The principal modification involves the consideration of extraction by plant roots. The general flow equation without root extraction for one dimension given by Hanks, Klute and Bresler (1969) is:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left( K(\theta) \frac{\partial H}{\partial z} \right) \qquad [30]$$

where $\theta$ is volumetric water content, t is time, z is depth, K is hydraulic conductivity, H is hydraulic head (sum of pressure head, h, and gravity head, z). The modification of the above equation by a plant root extraction term, A(z), gives:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left( K(\theta) \frac{\partial H}{\partial z} \right) + A(z) \qquad [31]$$

A(z) is the root extraction term or the sink term and depends on the root density function (the fraction of total active roots per unit volume of soil), soil conductivity, and the difference between pressure potential of water in the plant root and the pressure potential of soil water. Thus, the source term is defined as:

$$A(z) = \frac{[\text{Hroot} + (\text{RRES} \cdot z) - h(z) - S(z)] \cdot \text{RDF}(z) \cdot K(z)}{\Delta z} \qquad [32]$$

where Hroot is an effective water potential in the root at the soil surface where z is considered zero, RRES = $(1 + R_c)$. $R_c$ is a flow coefficient. When RRES is multiplied by z, the product will account for the gravity term and friction loss in the root water potential, so that root water potential at depth z is higher than the root water potential at the surface (Hroot) by a gravity term and friction loss term, (assuming that the friction loss in the root is independent of flow), h(z) is the soil matric potential at depth z, S(z) is the salt (osmotic) potential at depth z, RDF(z) is the proportion of total active roots in depth increment $\Delta z$, and K(z) is the hydraulic conductivity at depth z and it is a function of $\theta$. The soil matric potential, h(z) and the hydraulic conductivity, K(z) are assumed to be unique functions of soil water content (hysteresis ignored). The validity of the assumption that a unique relation of hydraulic conductivity to a volumetric water content, $K(\theta)$, exists is affected by hysteresis to a much lesser degree than is the K(h) function (Topp and Miller, 1966; Poulovassilis, 1969). The Hroot term is dependent on plant, climatic and soil conditions. The value of Hroot will depend on plant conditions since they govern the root distribution function, RDF(z). Hroot will depend on climatic conditions since they define potential transpiration, discussed in detail later. The value of Hroot will depend on soil conditions since h(z), K(z), S(z) will be soil properties (which will vary greatly from wet to dry soil). In the model, a value of Hroot is "hunted" for until the plant root extraction over the total profile is equal to potential transpiration provided the value of Hroot is higher than the value of plant water potential below which the plant will not go and thus wilting will occur (Hwilt). Thus, in the model Hroot is bounded on the wet end by (Hroot = 0.0) and the dry end by (Hroot = Hwilt).

The basic input data needed for the solution of the model are:

1. Soil properties h vs $\theta$ and K vs $\theta$ curves covering the range of water content to be encountered in the problem. The value of $\theta$-saturated and $\theta$-air dry must also be known.

2. $\theta$ vs z and S vs z at the beginning, or at $t = 0$.
3. Plant properties, root distribution function RDF(z) and the value of Hwilt.
4. Boundary and climatic properties which include the potential evapotranspiration and potential transpiration (from which potential evaporation can be deduced) as a function of time. These data will come basically from climatic variables of solar or net radiation, air temperature, air humidity, and wind speed and the proportion of ground covered by actively transpiring plants, or measurements of actual evapotranspiration. Potential infiltration, and precipitation as a function of time, are also needed.
5. Presence or absence of water table or layer restricting water flow at the lower boundary.

The output data that the solution of the model will give are:

1. Cumulative evapotranspiration, transpiration and evaporation as functions of time.
2. Volumetric soil water content, $\theta$, soil water potential, h, as functions of time and depth.
3. Cumulative water flow (upward or downward) through the lower boundary as a function of time.
4. The value of Hroot as a function of time.

Theory and Basis for the Model Development. Equation [30] results from combining Darcy's law for flow in an unsaturated soil with the continuity equation. The assumptions underlying this development are:

1. The fluid of interest, water, is continuously connected throughout the flow region and is incompressible.
2. Inertial forces are not significant as compared to viscous forces.
3. Flow is isothermal, vertical and one-dimensional.
4. Biological phenomena have no effect on soil water flow.
5. Air freely and instantaneously escapes from the system as water accumulates in it.

6. Soil does not shrink or swell as water content changes.
7. Water content either increases or decreases monotonically, thus avoiding the effects of hysteresis of soil properties.

Equation [31] is a modification of Equation [30], so the following assumptions were imposed for its development.

1. The roots are considered to be distributed in a continuous (but not necessarily uniform) manner.
2. No water is stored or consumed by the plant itself.

Equation [30] is a second-order, nonlinear, partial differential equation of parabolic type. Hanks and Bowers (1962) solved Equation [30] and developed an implicit-type finite-difference model for infiltration in layered soil. Hanks, Klute and Bresler (1969) modified the solution to estimate infiltration, redistribution, drainage, and evaporation as they occur under field conditions. Since the present model, Equation [31], is a modification of Equation [30], the generalized numerical solution is presented herein.

For one-dimensional vertical flow from Equation [31]

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left( K(\theta) \frac{\partial H}{\partial z} \right) + A(z) \qquad [33]$$

This equation needs to be transformed so that there is only one variable. Rubin (1966) mentioned three possible ways of doing this transformation. The transformation used was developed by Richards (1931) involving the left-hand side of Equation [33]:

$$C(\theta) = \frac{\partial \theta}{\partial h} \qquad [34]$$

where $C(\theta)$ is the soil water differential capacity. By the chain rule of calculus:

$$\frac{\partial \theta}{\partial t} = \frac{\partial \theta}{\partial h} \frac{\partial h}{\partial t} = C(\theta) \frac{\partial h}{\partial t} \qquad [35]$$

The substitution of Equation [35] into Equation [33] yields:

$$C(\theta)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial H}{\partial z}\right) + A(z) \qquad [36]$$

where the hydraulic head (H = h + z) is the only dependent variable.

The finite-difference form of the left-hand side term of Equation [36] is:

$$C(\theta)\frac{\partial h}{\partial t} = \left(\frac{C_i^j + C_i^{j-1}}{2}\right)\left(\frac{h_i^j - h_i^{j-1}}{\Delta T}\right) = C_i^{j-1/2}\left(\frac{h_i^j - h_i^{j-1}}{\Delta t}\right) \qquad [37]$$

where the subscript i represents the depth of a node, and the superscript j represents time.

The first step in finite differencing the first term on the right of Equation [36] is:

$$\frac{\partial}{\partial z}\left(K(\theta)\frac{\partial H}{\partial z}\right) = \frac{1}{\Delta z_3}\left(K\frac{\partial H}{\partial z}\bigg|_1 - K\frac{\partial H}{\partial z}\bigg|_2\right) \qquad [38]$$

where the identifier 1 is the mesh increment between nodes i-1 and i, the identifier 2 is the mesh increment between nodes i and i+1, and the identifier 3 is the mesh increment between nodes i-1 and i+1. Solving for the second and third term on the right-hand side of Equation [38] yields:

$$\begin{aligned} K\frac{\partial H}{\partial z}\bigg|_1 &= \left(\frac{K_1}{\Delta z_1}\right)\left(\frac{H_{i-1}^{j-1} + H_{i-1}^{j}}{2} - \frac{H_i^{j-1} + H_i^{j}}{2}\right) \\ K\frac{\partial H}{\partial z}\bigg|_2 &= \left(\frac{K_2}{\Delta z_2}\right)\left(\frac{H_i^{j-1} + H_i^{j}}{2} - \frac{H_{i+1}^{j-1} + H_{i+1}^{j}}{2}\right) \end{aligned} \qquad [39]$$

where $K_1$ is the average of the K values corresponding to the θ values at nodes (i-1, j-1), (i-1, j), (i, j-1) and (i, j), and $K_2$ is similarly associated with nodes (i, j-1), (i, j), (i+1, j-1) and (i+1, j). Another way of defining $K_1$ and $K_2$ that has been used is:

$$K_1 = K_{i-1/2}^{j-1/2} \quad \text{and} \quad K_2 = K_{i+1/2}^{j-1/2} \qquad [40]$$

The substitution of Equations [3°] and [40] into Equation [38] yields:

$$\frac{\partial}{\partial z}\left(K\frac{\partial H}{\partial z}\right) = \frac{1}{\Delta z_3}\left[\left(\frac{H_{i-1}^{j-1} + H_{i-1}^{j}}{2} - \frac{H_i^{j-1} + H_i^{j}}{2}\right)\frac{K_{i-1/2}^{j-1/2}}{\Delta z_1} - \left(\frac{H_i^{j-1} + H_i^{j}}{2} - \frac{H_{i+1}^{j-1} + H_{i+1}^{j}}{2}\right)\frac{K_{i+1/2}^{j-1/2}}{\Delta z_2}\right] \qquad [41]$$

Hanks and Bowers (1962), and Hanks, Klute and Bresler (1969) assumed constant depth increments, therefore, having:

$$\Delta z_1 = \Delta z_2 = \Delta z_3$$

In this model variable depth increments are considered, hence, $\Delta z_1$, $\Delta z_2$, and $\Delta z_3$ are not equal and are defined by:

$$\Delta z_1 = z_i - z_{i-1}; \ \Delta z_2 = z_{i+1} - z_i; \ \Delta z_3 = (z_{i+1} - z_{i-1})/2 \qquad [42]$$

Finally, the finite difference for the last term of Equation [36] is:

$$A_i^j = \frac{RDF_i \ (hp_i^j - hs_i^j) K_i^{j-1/2}}{\Delta z_3} \qquad [43]$$

where $hp_i^j = Hroot_0^j + (RRES)\, z_i$; and $hs_i^j = h_i^{j-1} + S_i^{j-1}$ [44]

Substituting Equations [37], [41], and [43] into Equation [36], and substituting for $H = h + z$, yields:

$$\left(\frac{h_i^j - h^{j-1}}{\Delta t}\right) C_i^{j-1/2} = \frac{1}{\Delta z_3} \left(\frac{h_{i-1}^{j-1} + h_{i-1}^{j} - h_i^{j-1} - h_i^{j} + 2z}{2\Delta z_1}\right) K_{i-1/2}^{j-1/2}$$

$$- \left(\frac{h_i^{j-1} + h_i^{j} - h_{i+1}^{j-1} - h_{i+1}^{j} + 2z}{2\Delta z_2}\right) K_{i+1/2}^{j-1/2} + RDF_i \, (hp_i^j - hs_i^j) K_i^{j-1/2} \qquad [45]$$

Equation [45] was the basic linear equation used to solve the model. This equation was programmed and solved by computer from a knowledge of appropriate boundary and initial conditions. Detailed explanation of the computer program and the solution of Equation [45] is presented in the following.

General Program Description. The FORTRAN program is given in Appendix B. The input and boundary data necessary for the program must be obtained for the specific crop and field condition for which the study is to be done. The program calculates the different variables for any time period and prints the output at any time interval required.

A step-by-step description of the program follows:

Step 1. The program reads and prints all the input and boundary data. These data include tables of conductivity and soil water pressure head as functions of water content, and root distribution as functions of depth. The potential water and salt flux at the surface, as well as potential evaporation and evapotranspiration as functions of time are also input data as are the maximum and minimum plant water potential. Other input information needed are the initial time increment to be used, the upper and lower limits on pressure head and water content (that is, saturation and air dry), the length of time the computation is to run, and the condition of the lower boundary (two conditions, a constant pressure head or no flux are provided).

Step 2. The diffusivity as a function of water content is computed and printed, as well as the pressure head as a function of water content at the different depth increments.

Step 3. The subroutine "plot" is called and water and salt content versus depth are plotted for the first time increment.

Step 4. From the initial water content as a function of depth, values of hydraulic conductivity as a function of depth are computed by the procedure outlined by Hanks and Bowers (1962). Values of the specific water capacity ($C = \Delta\theta/\Delta h$) as function of depth are computed from the water content and the pressure head-water content relations. A surface pressure head is computed to give the estimated flux at the surface in conformance with boundary conditions applying at the time using the following equation:

$$ER = \frac{(h_0^{J+1} + h_0^{J} - h_1^{J+1} - h_1^{J} + \Delta z) K_{1/2}^{J+1/2}}{2\Delta z} \qquad [46]$$

where ER is the flux at the surface, $h_0^{J+1}$ and $h_0^{J}$ are the pressure heads at the surface at the end and beginning of the time interval, $h_1^{J+1}$ and $h_1^{J}$ are the pressure heads at depth $\Delta z$ from the surface at the beginning and end of the time interval and $K_{1/2}^{J+1/2}$ is the hydraulic conductivity assumed constant over the time interval and applying between the surface and $z = \Delta z$. The surface pressure head is allowed to vary only between limits (that is, saturation or air dry). So the computed flux may be different from the potential flux. To solve Equation [46] a value of $h_0^{J+1}$ is assumed ($h_0^{J+1}$ = Hdry, if it is evaporation, $h_0^{J+1}$ = Hwet if it is precipitation) since it has not been computed yet.

Step 5. A value of Hroot is hunted that satisfies the condition (Sink $\leq$ potential ET of the plant, Sink is the cumulative root extraction). Hroot is allowed to vary only between limits (i.e., Hlow $\leq$ Hroot $\leq$ Hhi). A value of Hroot is assumed (Hroot = $h_1^{J}$) to start with since it is not computed yet. If precipitation is taking place, root extraction is assumed zero. If evaporation is taking place, then the cumulative root extraction is printed using Equation [43].

Step 6. The tridiagonal matrix is solved for the pressure head at the end of the time interval at each depth increment as described by Hanks and Bowers (1962). The only difference is $\Delta z$ is variable in the model used herein.

Step 7. The water content at each depth increment is computed from a knowledge of pressure head at each depth increment and water capacity as functions of depth and pressure head-water content relations, using the following formula:

$$\theta_i^{J+1} = C_i^J [h_i^{J+1} - h_i^J] + \theta_i^J \qquad [47]$$

The values of $h_i^{J+1}$ and $h_i^J$ are computed in Step 6.

Step 8. The program tests the total change in water content ($\Sigma\Delta\theta \leq$ ConQ, where ConQ is the largest total water content change allowed for each computation). If $\Sigma\Delta\theta \geq$ ConQ, then the time is reduced by half and the program goes back to Step 6. If $\Sigma\Delta\theta \leq$ ConQ the program proceeds to Step 9.

Step 9. The program computes the water flux at the surface and at the bottom boundaries.

Step 10. Cumulative values of various variables are computed, desired output is printed, a new $\Delta t$ is chosen that satisfies the condition $\Sigma\Delta\theta \leq$ ConQ, and the values of $h_i^{J+1}$ and $\theta_i^{J+1}$ taken as the new initial conditions $h_i^j$, $\theta_i^J$.

Step 11. The cumulative time is checked to adjust the potential boundary conditions if necessary. The process is repeated from Step 4 above until completion.

## Salt Model

The present model is essentially the combination of the model for water and salt flow by Bresler and Hanks (1969) and Dutt et al. (1971) models for solubility of minerals and exchange between the solution and solid phase. The essential features of the water flow model were discussed earlier. One-dimensional flow is considered in the model.

The rate of flow of salts at any plane in the direction of flow may be given by the equation

$$\left(\frac{\partial(\theta c)}{\partial t}\right)_z = \left(\frac{\partial}{\partial z}\left(\theta D\frac{\partial c}{\partial z}\right) - \frac{\partial(\bar{v}c)}{\partial z} + S\right)_z \qquad [48]$$

The first term on the right, in the above equation, represents the contribution from diffusion to the flow of solute and the second term represents the contribution from viscous flow. S is the sink or source term due to solubility of minerals and exchange of ions in solution with solid phase. Each component of Equation [48] is discussed separately.

Mass Flow of Salts. If the dispersion is absent and no sink or source exists, the flow of salt is due to the mass flow of water expressed as

$$\left(\frac{\partial(\theta c)}{\partial t}\right)_z = -\left(\frac{\partial(\bar{v}c)}{\partial z}\right)_z \qquad [49]$$

Numerical approximation of Equation [49] leads to

$$\frac{\theta_i^j c_i^j - c_i^{j-1}\theta_i^{j-1}}{\Delta t} = -\frac{\bar{v}_i^{j-1/2} c_i^{j-1/2} - \bar{v}_{i-1}^{j-1/2} c_{i-1}^{j-1/2}}{\Delta z} \qquad [50]$$

with the approximation, $c_i^{j-1/2} = c_i^{j-1}$ and $c_{i-1}^{j-1/2} = c_{i-1}^{j-1}$, Equation [50] reduces to

$$c_i^j = \left((\bar{v}_{i-1}^{j-1/2} c_{i-1}^{j-1} - \bar{v}_i^{j-1/2} c_i^{j-1})\frac{\Delta t}{\Delta z} + c_i^{j-1}\theta_i^{j-1}\right) \Big/ \theta_i^j \qquad [51]$$

Equation [51] and its modification are used to compute the mass flow of salt due to water.

Dispersion of Salts. If there is no dispersion, there should be piston flow of salts and sharp boundary in the salt distribution should exist at the wetting front. Since the numerical approximation involves the mixing of solutions and then averaging over a new water content (Equation [51]) a diffuse salt boundary exists at the wetting front. Although in the present model dispersion is ignored explicitly, the mixing of salt indicates a "built in" dispersion in the numerical method of salt flow.

Sink or Source Term. The concentration of salts at each depth is modified due to the chemical reactions like precipitation or dissolution of minerals and exchange between ions in solution and soil matrix. Both these processes contribute to the source or sink term in Equation [48].

Dissolution or Precipitation of Gypsum. A slightly soluble salt often present or added to the soil is gypsum. An equation relating gypsum to other constituents in soil is

$$CaSO_4 \cdot 2H_2O \rightleftharpoons Ca^{++} + SO_4^{--} + 2H_2O \qquad [52]$$

The solubility of gypsum is described by the solubility product constant concept

$$Ksp = a_{Ca}\, a_{SO_4} = c_{Ca}\, c_{SO_4}\, \gamma^2 = 2.4 \times 10^{-5} \qquad [53]$$

where Ksp is the solubility product constant, a is the activity of the ions designated, $\gamma$ is the activity coefficients of divalent ions ($\gamma_{Ca} = \gamma_{SO_4}$), and c is the equilibrium concentration of ions designated which are defined further as follows.

Let x moles per liter of $Ca^{++}$ and $SO_4^{--}$ that dissolve or precipitate and $c^o_{Ca}$, $c^o_{SO_4}$ are the initial molar concentrations of $Ca^{++}$ and $SO_4^{--}$, respectively. Then the change in relative composition of $Ca^{++}$ and $SO_4^{--}$ is

$$c_{Ca} = c^o_{Ca} + x \qquad [54]$$

$$c_{SO_4} = c^o_{SO_4} + x \qquad [55]$$

Combining Equations [54] and [55] with Equation [53], results in an equation of the form

$$x^2 + Bx + C = 0 \qquad [56]$$

where

$$B = c^o_{Ca} + c^o_{SO_4}$$

$$C = c^o_{Ca}\, c^o_{SO_4} - Ksp/\gamma^2$$

Equation [56] can be solved for x.

Undissociated Ca and Mg Sulfate. In addition to the dissolution or precipitation of gypsum, the $CaSO_4$, $Ca^{++}$, $SO_4^{--}$, $H_2O$ system involves the formation of undissociated $CaSO_4$. The dissociation constant $K_{[CaSO^o_4]}$ of ion-pair is defined as

$$K_{[CaSO^o_4]} = c_{Ca}\, c_{SO_4}\, \gamma^2 / c_{CaSO^o_4}\, \gamma \qquad [57]$$

where $c_{CaSO^o_4}$ is the molar concentration of the ion-pairs and $\gamma$ for ion-pairs is taken as unity.

Let $x_1$ be the moles per liter of $Ca^{++}$ and $SO_4^{--}$ which forms undissociated $CaSO_4$. If the initial concentration of $CaSO^o_4$ ion-pair is $c^o_{CaSO^o_4}$ then the change in concentration will be

$$c_{Ca} = c^o_{Ca} - x_1 \qquad [58]$$

$$c_{SO_4} = c^o_{SO_4} - x_1 \qquad [59]$$

$$c_{CaSO_4^o} = c^o_{CaSO_4^o} + x_1 \qquad [60]$$

when Equations [58], [59], and [60] are combined with Equation [57], rearrangement yields an equation of the form

$$Ax_1^2 + Bx_1 + C = 0 \qquad [61]$$

The chemistry of undissociated $MgSO_4$ is similar to $CaSO_4$ and results in an equation similar to Equation [61], where

$$A = \gamma^2$$

$$B = -\left( K_{[CaSO_4^o] \text{ or } [MgSO_4^o]} + \gamma^2 \, c^o_{Ca \text{ or } Mg} + \gamma^2 \, c^o_{SO_4} \right)$$

$$C = \gamma^2 \, c^o_{Ca \text{ or } Mg} \, c^o_{SO_4} - K_{[CaSO_4^o] \text{ or } [MgSO_4^o]} \, c^o_{CaSO_4^o \text{ or } MgSO_4^o}$$

Equation [61] can be solved for $x_1$. When the system contains gypsum, the undissociated $CaSO_4$ becomes constant

$$c_{CaSO_4^o} = Ksp/K_{[CaSO_4^o]} \qquad [62]$$

Dissolution or Precipitation of Lime. An equation relating to the dissociation of lime in water with its constituent is shown as

$$CaCO_3 \rightleftarrows Ca^{++} + CO_3^{--} \qquad [63]$$

and the solubility of calcite is usually described by the solubility product constant Ksp:

$$Ksp = a_{Ca} \, a_{CO_3} \qquad [64]$$

where a is the activity of ions designated by the subscript. Since $CO_3^{--}$ concentration is a function of partial pressure, and $HCO_3$ concentration is usually the predominant form in which $CO_2$ occurs in soil water systems, it is more convenient to consider the following reactions.

$$H_2CO_3 + CaCO_3 \rightleftarrows Ca^{++} + 2HCO_3^- \qquad [65]$$

$$K = a_{Ca} a^2_{HCO_3} / a_{H_2CO_3} \qquad [66]$$

If an equilibrium system is under constant pressure of $CO_2$ and if the activity coefficient of non-charged species ($H_2CO_3$) is unity, Equation [66] becomes

$$Z = K c_{H_2CO_3} = a_{Ca} a^2_{HCO_3} \qquad [67]$$

$$ZE = Z/\gamma_{Ca} \gamma^2_{HCO_3} = c_{Ca} c^2_{HCO_3} \qquad [68]$$

where $\gamma$ is the activity of association.

It has been pointed out by Olsen and Watanabe (1959) that the solubility of $CaCO_3$ in the soil is different from pure calcite, and the $H_2CO_3$ content in the soil solution is variable at different moisture contents. This in turn means that the value of Z, in the soil, varies with water content. A comparison of Equation [64] with Equations [67] and [68] shows Z and ZE to be equivalent to the solubility product constant. Dutt et al. (1971) determined the following relationship between Z and water content:

$$\log Z = -1.68 \log W - 4.46 \qquad [69]$$

where W is water content by weight expressed as percent. The same relation is used in the present model. ZE is then estimated from Equation [68].

Using the same argument as in the case of solubility of gypsum that $x_2$ is the moles per liter of $Ca^{++}$ that dissolves or precipitates, then the equilibrium concentration of $Ca^{++}$ and $HCO_3^-$ is

$$c_{Ca} = c^{o}_{Ca} + x_2 \qquad [70]$$

$$c_{HCO_3} = c^{o}_{HCO_3} + 2x_2 \qquad [71]$$

Substituting Equations [70] and [71] into Equation [68] results in a cubic equation

$$4x_2^3 + B\,x_2^2 + C\,x_2 + D = 0 \qquad [72]$$

where

$$B = 4\left(c^{o}_{Ca} + c^{o}_{HCO_3}\right)$$

$$C = c^{o\,2}_{HCO_3} + 4\,c^{o}_{Ca}\,c^{o}_{HCO_3}$$

$$D = c^{o}_{HCO_3} \cdot c^{o}_{Ca} - ZE$$

Equation [72] can be solved for $x_2$ by Newton Raphson iteration method.

Cation Exchange. An equation that described Ca-Mg exchange is

$$a_{Ca}/a_{Mg} = K_{Ca-Mg}\,E_{Ca}/E_{Mg} \qquad [73]$$

where $K_{Ca-Mg}$ is the exchange coefficient for Ca and Mg. Let y moles of $Mg^{++}$ per gm of soil go into solution or be adsorbed. Let the initial concentration of $Ca^{++}$ and $Mg^{++}$ be $c^{o}_{Ca}$ and $c^{o}_{Mg}$ moles/liter in the solution phase and $E^{o}_{Ca}$, $E^{o}_{Mg}$ be moles/gm adsorbed on the soil matrix. The change in the relative composition of $Ca^{++}$ and $Mg^{++}$ from the interaction of solution and adsorbed phase is then

$$E_{Ca} = E^{o}_{Ca} - y \qquad [74]$$

$$E_{Mg} = E^{o}_{Mg} + y \qquad [75]$$

$$c_{Ca} = c^{o}_{Ca} + \beta y \qquad [76]$$

$$c_{Mg} = c^{o}_{Mg} - \beta y \qquad [77]$$

where β is the ratio of gm of soil to liter of solution. Combining Equations [74] to [77] with Equation [73] results in quadratic expression

$$Ay^{2} + By + C = 0 \qquad [78]$$

where

$$A = \beta\left(1 - K_{Ca-Mg}\right)$$

$$B = \beta\left(F^{o}{}_{g} + K_{Ca-Mg} E^{o}_{Ca}\right) + c^{o}_{Ca} + K_{Ca-Mg}\, c^{o}_{Mg}$$

$$C = c^{o}_{Ca} E^{o}_{Mg} - K_{Ca-Mg}\, c^{o}_{Mg} E^{o}_{Mg}$$

Equation [78] can be solved for y.

Gapon's equation was used to describe the non-symmetrical exchange between Ca and Na

$$\sqrt{a_{Ca}}/a_{Na} = K_{Ca-Na} E_{Ca}/E_{Na} \qquad [79]$$

Using the same reasoning for calculating the equilibrium concentration as in the case of Ca-Mg exchange, Equation [79] reduces to

$$Ay_1^4 + By_1^3 + Cy_1^2 + Dy_1 + E = 0 \qquad [80]$$

where $y_1$ is the change in concentration required to reach equilibrium from initial concentration, and

$$A = -4\, K_{Ca-Na}\, \beta^2$$

$$B = 4\beta \left( \gamma_{1/2} + K^2_{Ca-Na}\, E^o_{Ca}\, \beta + K^2_{Ca-Na}\, c^o_{Na} \right)$$

where $\gamma_{1/2}$ is the ratio of activity coefficient of Ca to Na,

$$C = 4\gamma_{1/2} \left( c^o_{Ca} + E^o_{Na}\beta \right) - 4K^2_{Ca-Na}\beta\, E^o_{Ca} \left( \beta E^o_{Ca} + 2c^o_{Na} \right)$$
$$- K^2_{Ca-Na}\, c^{o^2}_{Na}$$

$$D = E^o_{Na}\gamma_{1/2} \left( 4c^o_{Ca} + E_{Na}\beta \right) + 2K^2_{Ca-Na}\, E^o_{Ca}\, c^o_{Na} \left( 2\beta E^o_{Na} + c^o_{Na} \right)$$

$$E = E^{o^2}_{Na}\, c^o_{Ca}\, \gamma_{1/2} - K^2_{Ca-Na}\, c^{o^2}_{Na}\, E^{o^2}_{Ca}$$

Equations [56], [61], [72], [78], and [80] are used to calculate the equilibrium concentrations.

Description of Computer Program. The computer model of Dutt et al. (1971) for solubility of minerals and exchange between ions in solution and soil was combined with the salt and water transport model of Bresler and Hanks (1969). The resultant model consists of a main program and five subprograms. The subprograms are designated as: (1) PLOT, (2) EXCH, (3) EQEXCH, (4) SALT, and (5) ACOF.

The complete FORTRAN program is listed in Appendix B. The main program does several things. First, it reads the initial and boundary conditions. The initial conditions in his experiment include the concentration of salts applied on the soil surface at the beginning of the experiment. Since the salts were applied in the powder form rather than in solution, it was assumed that they were soluble at the given water content of the soil. The program then calls for subroutine EQEXCH. This subroutine calculates $CaSO_4$, $MgSO_4$ ion-pairs and equilibrium concentration of exchangeable ions. The input and transformed data are then printed to provide the user with a record. Concurrently, the main program calls for subroutine PLOT which plots the water and salt content with depth. After setting various counters and initializing certain values, the program computes the new values of pressure head and water content.

The routine then executes a large outer loop for the number of depths in a profile. Within this loop the routine checks for the amount of water leaving or entering the top or bottom of a soil segment at a particular depth. If the amount of moisture flow is not negligible, subroutine SALT is called which computes the flow of salts due to mass flow of water. A check is then made to call the subroutine EXCH. The check insures that changes in concentration of ions due to solubility of minerals and exchange are calculated every hour rather than every $\Delta t$. No great difference was noted in the predicted values when subroutine EXCH was called each $\Delta t$. The counter for this check is initialized to zero after each call for subroutine EXCH.

Then the program increments the time counter with $\Delta t$ and initializes the old values with the recently computed values of the variables used in salt and water flow. The routine then calls for subroutine PLOT and prints the output.

A check is then made for the new boundary conditions and cumulative time for which the program is allowed to run. If the time equals the cumulative time it then stops after the subroutine PLOT is called and the needed output information is printed. Otherwise, it goes back to statement 16 and executes for the next $\Delta t$ increment.

The input data needed (besides that listed earlier for the water flow program) are as follows:

1. Activity coefficient-ionic strength tabular data covering the range of ionic strength encountered in the system.
2. Chemical composition-depth tabular data at the beginning (initial conditions). This involves the knowledge of the

chemical analysis of the important chemical species. At present, Ca, Mg, Na cations and Cl, $SO_4$, and $HCO_3$ anions are considered.

3. Chemical composition of the irrigation or rain water (boundary conditions).

The type of output data available is almost infinite. Consequently, a selection of the desired data (besides that listed earlier for the water flow model) is made from the following:

1. Chemical composition of the soil solution vs depth and time during the period.
2. Chemical composition of the water going into the water table or up from the water table as a function of time.

The EXCH subroutine is called in the main program approximately every hour (real time) or at each $\Delta t$ if $\Delta t$ is greater or equal to one hour. This implies that in a time of one hour equilibrium is established between the ions in the solution and solid phase. Adjustment in the concentration of different ions due to solubility of minerals and exchange with soil particles is made in this subroutine. The adjusted concentrations are then returned to the main program.

Since the concentrations of exchangeable cations are necessary to predict changes in soil solute composition and reliable analytical methods are not available when excess calcium carbonate is present, an improved method for their calculation is necessary. The EQEXCH subroutine calculates exchangeable ions from initial soil analysis. It also calculates the concentration of $Ca^{++}$, $Mg^{++}$, $SO_4^{--}$, $CaSO_4$ ion-pair and $MgSO_4$ ion-pair from their total analysis. Theory underlying this subroutine is discussed in the following sections.

Sulfate occurs in basic solution in more than one form. In addition to free sulfate ions, there are two forms which have been shown to be of importance in base saturated soil-water systems; these are undissociated, soluble $CaSO_4$ (Dutt, 1964) and $MgSO_4$ (Tanji and Doneen, 1966). Thus the total sulfate in solution is

$$c_{TSO_4} = c_{SO_4} + c_{CaSO_4} + c_{MgSO_4} \qquad [81]$$

Similarly, the total calcium, $c_{TCa}$ and magnesium, $c_{TMg}$ is

$$c_{TCa} = c_{Ca} + c_{CaSO_4} \tag{82}$$

$$c_{TMg} = c_{Mg} + c_{MgSO_4} \tag{83}$$

The thermodynamic equilibrium constant for equilibrium between the undissociated species in solution and the appropriate ions is

$$K_{[CaSO_4^o]} = \frac{a_{Ca}\,a_{SO_4}}{a_{CaSO_4^o}} \tag{84}$$

and

$$K_{[mgSO_4^o]} = \frac{a_{Mg}\,a_{SO_4}}{a_{MgSO_4^o}} \tag{85}$$

Combining Equations [82] and [84], we get

$$c_{CaSO_4^o} = \frac{\gamma_{SO_4}\,\gamma_{Ca}\,c_{TCa}\,c_{SO_4}}{K_{[CaSO_4^o]} + \gamma_{Ca}\,\gamma_{SO_4}\,c_{SO_4}} \tag{86}$$

and similarly combining Equations [83] and [85], we get

$$c_{MgSO_4^o} = \frac{\gamma_{SO_4}\,\gamma_{Mg}\,c_{TMg}\,c_{SO_4}}{K_{[MgSO_4^o]} + \gamma_{Mg}\,\gamma_{SO_4}\,c_{SO_4}} \tag{87}$$

Combining Equation [81] with Equations [86] and [87] result in a cubic equation

$$Ax^3 + Bx^2 + Cx + C = 0 \tag{88}$$

where

$$x = c_{SO_4}$$

$$A = \gamma_2^{\,4} = \left(\gamma_{Ca}\gamma_{SO_4}\right)^2 = \left(\gamma_{Mg}\gamma_{SO_4}\right)^2$$

$$B = \gamma_2^{\,2} \left( (K_{[CaSO_4^o]} + K_{[MgSO_4^o]} + \gamma_2^{\,2} (c_{TCa} + c_{TMg} - c_{TSO_4}) \right)$$

$$C = K_{[CaSO_4^o]} K_{[MgSO_4^o]} + \gamma_2^{\,2} \left( c_{TMg} K_{[CaSO_4^o]} + c_{TCa} K_{[MgSO_4^o]} \right.$$

$$\left. - c_{TSO_4} K_{[CaSO_4^o]} + K_{[MgSO_4^o]} \right)$$

$$D = c_{TSO_4} K_{[MgSO_4^o]} K_{[CaSO_4^o]}$$

Equation [88] is solved by Newton Raphson method for $c_{SO_4}$. Concentrations of $Ca^{++}$ and $Mg^{++}$ are calculated using Equations [82], [83], [86], and [87].

Equations [73] and [79] are used to describe Ca-Mg and Ca-Na exchange in this model. If calcium, magnesium, and sodium are the only cations in the soil then

$$E_T = E_{Ca} + E_{Mg} + E_{Na} \qquad [89]$$

where $E_T$ is the cation exchange capacity. Combining Equations [73] and [79] with Equation [89] results in

$$E_{Ca} = \frac{E_T}{\frac{a_{Na}}{K_{Na-Ca}\sqrt{a_{Ca}}} + \frac{K_{Ca-Mg}\ a_{Mg}}{a_{Ca}} + 1} \qquad [90]$$

Exchangeable cation concentrations are calculated using Equations [79], [89], and [90]. The EQEXCH subroutine is called only once at the start in the main program.

The SALT subroutine calculates the changes in salt concentration due to mass flow of water. The mass flow of salt is computed by Equation [49].

The ACOF subroutine is called in both subroutines EQEXCH and EXCH. It calculates the activity coefficients of monovalent and divalent ions. In dilute solution, activity coefficients of ions can be adequately described by a modified form of Debye Hückel law for mixed electrolytes

$$\log \gamma_i = - \frac{0.509\ Z_i^2 \sqrt{I}}{1 + \sqrt{I}} \qquad [91]$$

where

$$I = \frac{1}{2\rho_o} \sum_{i=1}^{n} c_i Z_i^2 \qquad [92]$$

where i is the ion species of interest, n is the total number of ion species in solution, Z is the valence, and $\rho_o$ is density of the solution ($\rho_o = 1$).

In concentrated salt solution as used in the present experiments, table values (Robinson and Stokes, 1955) of activity coefficients are used. Activity coefficients of individual ions are calculated from the mean molal activity coefficient of salts using the following relationship

$$\gamma_{Ca} = \frac{\gamma_{\pm}^3 CaCl_2}{\gamma_{\pm}^2 KCl} \qquad [93]$$

$$\gamma_{Na} = \frac{\gamma_{\pm}^{2}\ NaCl}{\gamma_{\pm} KCl} \qquad [94]$$

As a first approximation, it is assumed

$$\gamma_{Ca^{++}} = \gamma_{Mg^{++}} = \gamma_{SO_4^{--}} \qquad [95]$$

$$\gamma_{Na^{+}} = \gamma_{HCO_3^{-}} \qquad [96]$$

This subroutine uses the table value of divalent or monovalent ion activity coefficient corresponding to a given ionic (I) strength.

# SECTION VI

# TESTING OF MODELS

Before the details of the testing of the models are discussed descriptions are given of the field facilities and type of data collected and the laboratory experiments and type of data collected.

## Field Facilities and Data

The field work was conducted on the Hullinger farm in the Ashley Valley near Vernal, Utah (Figure 2). The farm was leased on a year-to-year basis beginning October 1, 1969, with the University having the option to renew the lease for a period of at least ten years. This type of a lease agreement assured the availability of the farm for research purposes for a ten year period. The total area of the farm is approximately 52 acres, of which about 35 acres lying north of the Naples Drain was the study area. A map of the farm is shown in Figure 3.

### Drainage System

Construction of a tile drainage system was completed in March, 1970. The system consisted of six separate drains discharging into the natural drainage channel as shown on the map of Figure 3. Each drain had a manhole designed to accommodate a V-notch weir and water stage recorder (Type A-35, Leupold & Stevens) for measuring and recording the drain discharge and to provide access for water quality measurements of drainage effluent.

Drains 1, 2, 3, 4, and 5 are spaced 200 feet apart. Drain 6 is 350 feet west of drain 5. The depth of drains averages approximately five feet from ground surface to the invert of the tile. The drains are constructed of six-inch concrete tongue and groove pipe in 36-inch lengths with a minimum of a four-inch gravel envelope surrounding the pipe. Nearly all of the trench was dug with a trenching machine which left approximately a two-foot width of trench, hence, the gravel envelope along the side of the pipe is thicker than the minimum of four inches. About 400 feet east of drain 1 and parallel to it, there exists a deep tile drain which has its primary function the drainage of the Vernal Municipal Airport runway. The drain is estimated to be in excess of eight feet deep along the eastern boundary of the Hullinger farm.

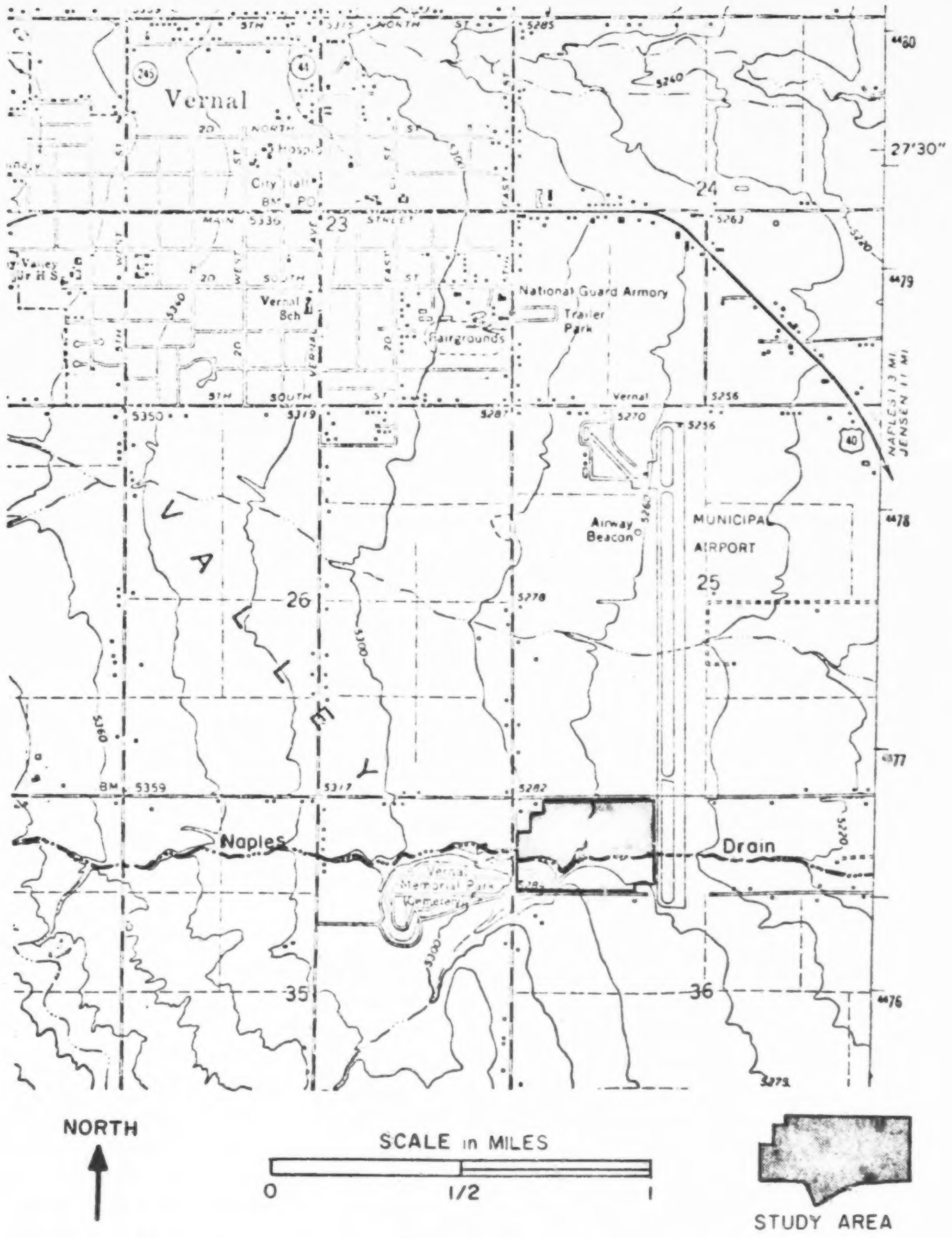
Vernal
5TH NORTH ST
20 NORTH ST
Hospital
City Hall
BM PO
MAIN 5336 STREET
23
24
20 SOUTH ST
5TH SOUTH ST
Vernal Bch
National Guard Armory
Trailer Park
Fairgrounds
Vernal
5350
5319
5287
5270
5256
5263
5285
5260
Airway Beacon
MUNICIPAL AIRPORT
25
26
V A L L E Y
5300
5360
5278
BM 5359
5317
5282
Naples
Drain
5270
Vernal Memorial Park Cemetery
35
36
5273
27'30"
NAPLES 1.3 MI
JENSEN 11 MI
40
NORTH
SCALE in MILES
0
1/2
1
STUDY AREA

Figure 2. Location map, Hullinger farm, Vernal, Utah.

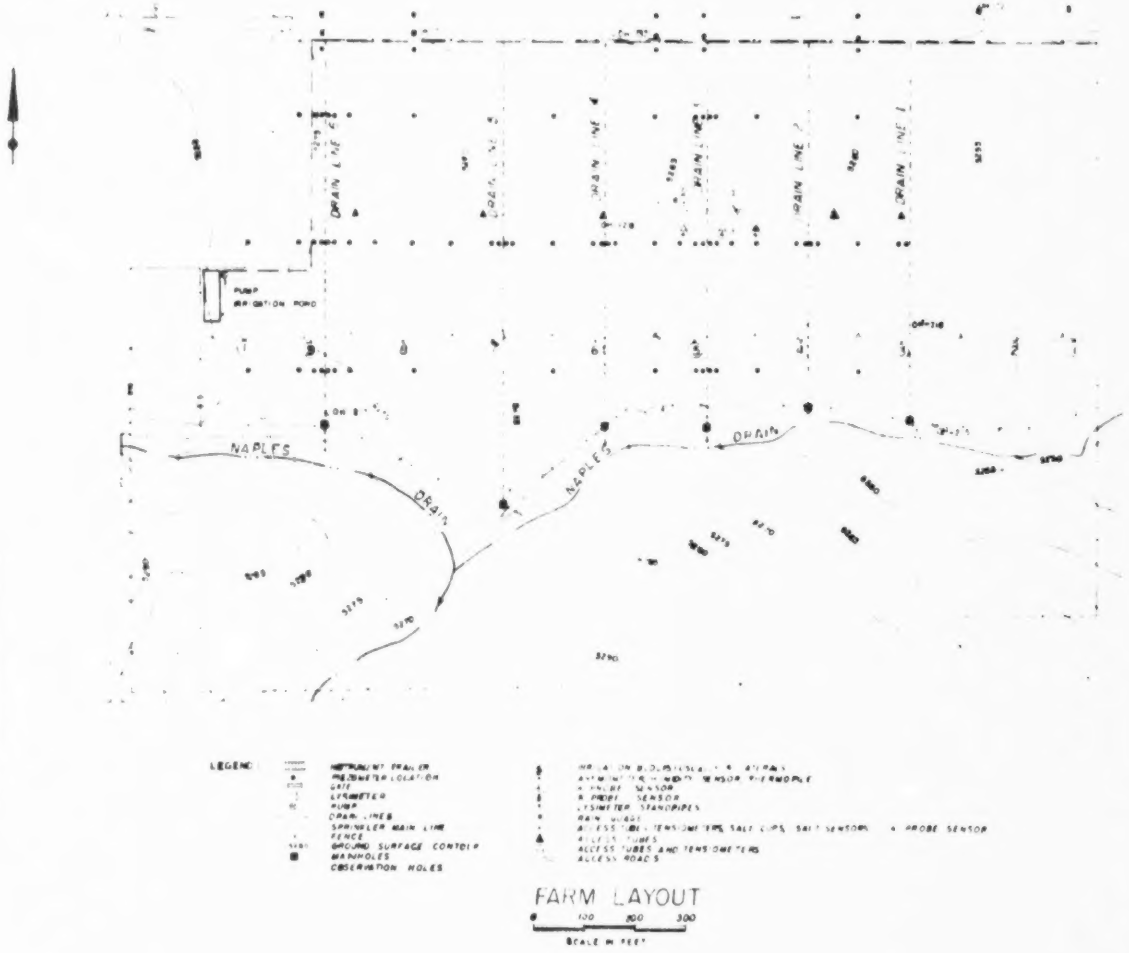
DRAIN LINE 6
DRAIN LINE 5
DRAIN LINE 4
DRAIN LINE 3
DRAIN LINE 2
DRAIN LINE 1
PUMP
IRRIGATION POND
NAPLES
DRAIN
NAPLES
DRAIN
LEGEND
INSTRUMENT TRAILER
PIEZOMETER LOCATION
GATE
LYSIMETER
PUMP
DRAIN LINES
SPRINKLER MAIN LINE
FENCE
GROUND SURFACE CONTOUR
MANHOLES
OBSERVATION HOLES
RAIN GAUGE
ACCESS TUBES
ACCESS TUBES AND TENSIOMETERS
ACCESS ROADS
FARM LAYOUT
0
100
200
300
SCALE IN FEET

Figure 3. Farm layout.

Reproduced from
best available copy.

## Piezometers and Observation Holes

The solid black dots on Figure 3 indicate the location of sets of piezometers which are used to measure groundwater potential gradients, the direction of groundwater flow, and the water table elevation. Each set has pipes extending to depths of 6, 9, and 12 feet below ground surface. It was expected that the primary direction of groundwater flow would be to the east, essentially parallel to ground surface. Although the amount of irrigation water applied to the farm was controlled easily by the sprinkler system, surrounding farmers continued to use a flooding method of irrigation. Hence, groundwater was also expected to move toward the farm from the north. The piezometers were located to detect these groundwater movements.

Figure 3 also shows the location of observation holes used to sample groundwater quality. The observation holes labeled B and C north of the road penetrate to shale as do the seven unlabeled holes around the edge of the study area.

## Sprinkler System

A solid-set automated sprinkler system was installed on the farm. The system has electric valves which are wired to give irrigation in blocks of four laterals (two on either side of a drain) operating simultaneously. The blocks are indicated near the center of Figure 3 by the brackets and circled numbers 1 through 9. The laterals run north and south, parallel to the drains, and are spaced 50 feet apart. Sprinklers are spaced thirty feet apart on each lateral. All of the system is above ground. The system is designed such that the time of irrigation of any one block can be set from a few minutes up to 24 hours, and the system will automatically sequence from one block to the next. Any one or more blocks can be completely skipped in an irrigation sequence.

The sprinkler system is designed to deliver approximately one quarter inch of water per hour and is powered by a 25-horsepower, 3 phase electric pump which removes water from an irrigation pond holding enough water for two hours of operation of the system. The pond is lined with a 20-mil thick black PVC exposed lining and has an overflow which will allow excess water to spill into the Naples Drain. Electrical power is supplied separately to the instrument trailer located on the north edge of the farm. This power operates the automated valves and other instrumentation.

## Crops History

Prior to the University's operating the farm, the crops consisted mainly of irrigated pasture with a small acreage of oats and alfalfa in the area immediately north of the Naples Drain. The entire farm was flood irrigated. In the first week of June, 1970, the 35 acres north of the Naples Drain was seeded to alfalfa with oats as a nurse crop and irrigation with the sprinkler system began in the latter part of June. Prior to seeding, soil samples were taken which were analyzed for nutrient availability. Phosphate was applied at the recommended rate of about 90 pounds per acre and 35 pounds of available nitrogen were applied to provide good growth of the oats. The crop was field chopped in the late dough stage.

Due to a rather uneven stand of alfalfa, alfalfa was reseeded with a drill in the existing stand in the spring of 1971. Until the first cutting, rather frequent irrigations were applied to obtain a good alfalfa stand. Thereafter various irrigation frequencies were used and data were collected to field test the models.

## Evapotranspiration

Actual evapotranspiration was measured by means of lysimeters. Potential evaporation ($E_F$) was calculated from a combination equation developed by Penman (1963) using daily values of a minimum number of meteorological parameters. The required meteorological data consist of:

1. Daily maximum and minimum air temperatures.
2. Daily solar radiation.
3. Average dew point temperature.
4. Daily wind run at a known height.

The combination equation is:

$$E_F = \frac{\Delta}{\Delta + \gamma} (Rn) + \frac{\gamma}{\Delta + \gamma} (15.36) (1 + 0.01 w) (e_s - e_a) \qquad [97]$$

where $\Delta$ is the slope of the saturation vapor pressure-temperature curve, $\gamma$ is the psychrometric constant equal to 0.57 for Vernal conditions, w is the total daily wind run in miles, $e_s$ is the mean saturation vapor pressure in mb, $e_a$ is the saturation vapor pressure at mean dew point temperature in mb, Rn is the daily net radiation in cal $cm^{-2}\ T^{-1}$. The parameters $\Delta/(\Delta + \gamma)$ and $\gamma/(\Delta + \gamma)$ are mean air temperature sensitive factors whose sum is 1.0 (Jensen, 1966). It was assumed that soil heat flow was negligible.

The net radiation (Rn) was calculated from

$$Rn = (1 - \rho)R - R_L \tag{98}$$

where ρ (albedo) is reflection coefficient assumed equal to 0.20, and R is total incoming solar radiation in cal $cm^{-2}\ T^{-1}$. $R_L$, the net long wave back radiation in cal $cm^{-2}\ T^{-1}$ was calculated from:

$$R_L = [0.98 - (0.67 + 0.044e_a^{1/2})]\ [0.5855\ (10^{-7})]\ [(T_{max} + 273)^4 + (T_{min} + 273)^4] \tag{99}$$

where $T_{max}$ and $T_{min}$ are maximum and minimum air temperature °C, respectively. The data for actual and potential evapotranspiration were measured periodically twice a day.

Potential evapotranspiration for a given agricultural crop can be related to potential evaporation from a free water surface by:

$$E_p = K_c E_F \tag{100}$$

where $E_p$ is potential evapotranspiration, $K_c$ is crop factor (dimensionless), and $E_F$ is potential evaporation from free water surface. Equation [100] is applicable when soil water is not limiting.

Soil water content profiles were arrived at by measuring the water content of the soil at different depths before and after each irrigation using neutron and gamma scattering devices. Details of these measurements are given later.

Lysimeters

Two lysimeters 4 by 4 by 4 feet were installed in the Vernal farm. The lysimeters used were similar to those developed by Hanks and Shawcroft (1965). The total weight of the lysimeter was distributed over the two wooden blocks which sat on two rubber bags. The pressure of the water in the bags was equal to the total weight of the inner tank and contents divided by the area of the two wooden blocks. The wooden blocks were used to maintain a constant area over which the weight was distributed. The pressure was measured as the height of water in the standpipe (active tube). The "dummy" standpipe was used for temperature correction.

The change in weight of the lysimeter was due to evapotranspiration or precipitation. Moreover, the weight changes are most conveniently expressed as an equivalent depth of water. The equation expressing this relation was given by Hanks and Shawcroft (1965):

$$E_a = \Delta h \frac{A}{A_1} \frac{\rho_f}{\rho_w} \qquad [101]$$

where $E_a$ is evapotranspiration (or precipitation) in cm of water, $\Delta h$ is corrected change in height of fluid in standpipe, A is the area over which the weight is distributed, $A_1$ is the area of the bottom of the lysimeter, $\rho_f$ is the density of fluid in the standpipe, and $\rho_w$ is the density of water. In other words $(\frac{A}{A_1} \frac{\rho_f}{\rho_w})$ is the calibration coefficient of the lysimeter. In the case of the lysimeters installed for this experiment, it was equal to 0.53. The value of $\Delta h$ was measured from readings of the standpipe (active and dummy) at two different times. Hence, for the lysimeters used in the field experiment, Equation [101] becomes:

$$E_a = 0.53 [(A_1 - A_2) - (D_1 - D_2)] \qquad [102]$$

where $A_1$ and $D_1$ are readings of active and dummy standpipes at first period, and $A_2$ and $D_2$ are readings of active and dummy standpipes at second period, respectively. The data collected is presented in Appendix C, Table 34.

## Neutron Probe

Soil moisture determinations were made by the neutron scattering method. Equipment manufactured by Troxler Electronic Laboratories of Raleigh, North Carolina was utilized. The probe was Model 1255, 1.865 inches diameter with americuim-beryllium as a fast neutron source, and with a nominal activity level of 100 millicuries. The scaler was Model 2651 with count indicators and was battery operated.

Moisture content on a volume basis was determined by taking neutron counts at the desired depths, comparing them to the neutron counts through the standard and then applying the calibration equation. Readings at various depths were made by inserting the neutron probe into access tubes penetrating the root zone to a depth of 7.0 feet. These access tubes were made of two-inch outside diameter aluminum pipes, placed vertically in the soil by augering. While not in use each tube was closed by a rubber stopper to prevent the tube from filling with water while irrigation was taking place.

The probe was calibrated to compare results with a general calibration supplied by the manufacturer. One metal barrel 46 cm diameter and 56 cm high was filled up to 45 cm with air dry soil. Another barrel was filled with field moist soil and a third barrel was filled with field moist soil brought to saturation and then drained for 48 hours. The moisture contents of the soil were determined gravimetrically and counts per minute of the neutron probe were taken at 20, 23, and 25 cm depth in each of the barrels and the average count computed. The ratio of the counts per minute in the soil to the shield standard for each soil was calculated. The results are tabulated in Table 2.

Table 2. Results of calibration of the neutron probe.

| Sample | Relative counts R | Water content by weight | Bulk density $gm/cm^3$ | Water content by volume $\theta$ |
|---|---|---|---|---|
| Air dry soil | 0.062 | 0.013 | 1.482 | 0.019 |
| Field moist soil | 0.562 | 0.159 | 1.354 | 0.216 |
| Field moist soil (before saturation) | 0.601 | 0.137 | 1.548 | 0.212 |
| Field moist soil (after drainage) | 1.089 | 0.239 | 1.548 | 0.370 |

The barrel calibration resulted in the formula:

$$\theta = 0.3591\ R - 0.0038 \qquad [103]$$

as compared to

$$\theta = 0.4149\ R - 0.0410 \qquad [104]$$

supplied by the manufacturer. $\theta$ is water content by volume and R is the ratio of soil count rate to shield standard count rate. The differences between the calibration curves do not allow drawing a conclusion as to whether different soils require separate calibration curves as recommended by Mortier and Deboodt (1956), McGuinnes, Driebelbus, and Harold (1961), and Nimah (1968) or whether one calibration is enough, as reported by Gardner and Kirkham (1952). Equation [103] was used for moisture determination throughout this study. Tables 35 and 36, Appendix C, summarize the data collected during the 1971 growing season.

Gamma Probe

The two-probe gamma density gauge used in this study was manufactured by Troxler Electronic Laboratories of Raleigh, North Carolina. The two-probe density gauge was Model 2376 and used $^{137}Cs$ as a source of gamma photons of 661 Kev energy with a nominal activity level of five millicuries. The detector utilized a thallium activated sodium iodide crystal. The system used a pulse height analyzer which rejects all radiation above and below a 661 Kev energy level.

The count rate in the soil, I, is given by the following:

$$I = I_0\ [\exp(-(\mu_s \rho_b + \mu_w \theta \rho_w)\ \chi)] \qquad [105]$$

where $I_0$ is radiation intensity with no interference, $\rho_b$ is the bulk density of the soil, $\theta$ is the volumetric water content, $\rho_w$ is the density of water, and $\mu_s$ and $\mu_w$ are the mass absorption coefficients of oven dry soil and water, respectively, and $\chi$ is the thickness of the sample (cm). Accurate values of the mass absorption coefficients of the soil and the water are needed if Equation [105] is to be used for determining density and water content of the soil (Davidson, Biggar, and Nielsen, 1963). As the water content increases, the radiation passing through the sample decreases. It is apparent from Equation [105] that changes in the bulk density of the soil cause corresponding variation in the radiation intensity passing through the soil water system. If the bulk density is constant, changes in "I" from one period to the next are due to changes in water content. Although this is a major assumption of the method, it offers no limitation for many agricultural soils. Equation [105] requires a knowledge of $I_0$, $\mu_s$, $\mu_w$, $\rho_w$ and $\rho_b$ to calculate $\theta$ from detector count rate reading, I.

The attenuation coefficient or mass absorption of oven dry soil and water were determined for Mesa fine sandy loam and water. The procedure for determining them was essentially the same as given by Davidson, Biggar and Nielsen (1963). The attenuation coefficients for soil and water were measured as 0.065 and 0.067, respectively. These results are lower than those reported by Davidson, Biggar and Nielsen (1963) which were 0.077 (soil) and 0.082 (water). The reason for these differences is not known. Measurements on the other soils yielded almost identical lower results. Therefore, the values 0.065 (soil) and 0.067 (water) were used throughout this study. The processed data is shown in Appendix C, Tables 37 and 38.

## Climatic Data

A weather station was located on the farm, as shown in Figure 3. Measurements of global radiation, wind velocity, and wet and dry bulb temperatures were taken during the experiment.

Global radiation was measured by a radiometer Model No. 633, Science Associates, 230 Nassau St., Box 230, Princeton, N. J. It has a sensitivity of about 8 millivolts per cal $cm^{-2}$ $min^{-1}$, with an effective wavelength range of 0.3 to 2.0 microns. The measurements were recorded on an integrator using this formula:

$$R = 2.7775\ [(0.1016\ Dx) - (I)(min)] \qquad [106]$$

where R is total radiation, Dx is the difference in integrator readings at two different times, I is the average "zero" current intensity during the time interval, and min is the lapsed period in minutes between the time of measurements. The net radiation was calculated from the total radiation using Equation [98]. Data of R and computed $R_n$ and $R_L$ are shown in Table 39, Appendix C.

Wind velocity was measured at 200 cm above the soil surface by an anemometer (Science Associates, U.S. Weather Bureau Specification Number 450.6103). The anemometer consists of three conical cups of 2.75 inches in diameter mounted on a rotor with a turning diameter of 12.5 inches, a starting speed of 3 mph, and an accuracy of ± 1.5 mph to 70 mph. The measurements were taken by a totalizing remote electrical counter that was read twice daily. The data collected is tabulated in Table 39, Appendix C.

The wet and dry bulb temperatures were measured at about 200 cm height by a sling psychrometer (Science Associates, U.S. Weather Bureau Specification Number 450.1016). It utilized two matched thermometers, 9.5 inches long, accurate to $\pm 0.3^\circ$F above $0^\circ$F and $\pm 0.5^\circ$F below $0^\circ$F, mounted on a stainless steel backing. Measurements were made twice daily. Table 39, Appendix C, shows the data.

Daily maximum and minimum temperatures were measured at the weather station located at the Vernal Airport about 1500 feet east of the research farm.

The values of $e_s$ and $e_a$ (Equation [97]) were estimated from the following equations:

$$e_s = 6.10127 + 0.4538\ DB + 0.01217\ DB^2 + 0.004156\ DB^3 \qquad [107]$$

and

$$e_a = e_s - 0.57288\ (1 + 0.00115\ WB)(DB - WB) \qquad [108]$$

where DB and WB are dry and wet bulb temperatures in $^\circ$C. The data are tabulated in Table 39, Appendix C.

## Irrigation Data

During the 1970 season, with oats as the primary crop, the entire farm received the same schedule of irrigation. Conductivity recorders were used to measure the EC of the applied water. Considerable difficulty was experienced with the battery powered recorders in the field. Periodic measurements on samples brought into the laboratory indicated many malfunctions of the recorders.

In 1971, due to reseeding the alfalfa, rather light frequent irrigations were used until the first cutting in June as shown in Table 34, Appendix C. At the time of the first cutting, irrigation schedules were devised for the various irrigation blocks. The desired schedules for the period between the first and second cuttings of alfalfa are indicated in Table 3. Table 4 gives the desired schedules between the second and third cuttings. The schedules were designed in an attempt to eliminate the necessity of irrigating on weekends. The EC of the applied water was measured in the field during 1971 with a portable conductivity meter. The actual timing, depth, and EC of the irrigations are given in Tables 16 through 20, later in this section. Typical composition of the irrigation water is given in Table 7 later in this section.

Table 3. Irrigation schedules for various irrigation blocks on the Hullinger farm between first and second cuttings of alfalfa in 1971.

| Block | Irrigation Interval (days) | Block | Irrigation Interval (days) | Block | Irrigation Interval (days) |
|---|---|---|---|---|---|
| 1 | * | 4 | 7 | 7 | 17.5 |
| 2 | * | 5 | 10.5 | 8 | 17.5 |
| 3 | 3.5 | 6 | 14 | 9 | * |

* Definite schedule not attempted

## Drain Discharge

In 1970, water stage recorders were installed in the manholes of drains 4, 5, and 6. The 12-inch float of water stage recorder was centered in a 14-inch diameter stilling well attached to a weir box with a standard $90^{o}$ V-notch weir. During 1970, drains 1, 2 and 3 did not discharge water into the Naples Drain. In the spring of 1971, water stage recorders were installed in the manholes of drains 2, 3, 4, 5, and 6. Data collected on the discharge of the drains is shown graphically in Figures 56 through 59 of Appendix C.

Table 4. Irrigation schedules for various irrigation blocks on the Hullinger farm between second and third cuttings of alfalfa in 1971.

| Block | Irrigation Interval (days) | Block | Irrigation Interval (days) | Block | Irrigation Interval (days) |
|---|---|---|---|---|---|
| 1 | * | 4 | 14 | 7 | 3.5 |
| 2 | * | 5 | 10.5 | 8 | 3.5 |
| 3 | 17.5 | 6 | 7 | 9 | * |

* Definite schedule not attempted

During 1970 the conductivity recorders were also used on the drain effluent. The same problems as described above under "Irrigation Data" were encountered with the recorders. The details of the EC data for 1970 are considered unreliable and are not included in this report. In general the EC of the drain effluent ranged from 1.2 mmho/cm to 2.4 mmho/cm. In 1971, use of the recorders was abandoned and periodic measurements of EC were made in the field with the portable conductivity meter. Results for 1971 are given in Table 40, Appendix C. Typical composition of the drain effluent is given in Table 41 of Appendix C.

## Piezometric Data

The 80 sets of piezometers shown in Figure 3 were read about weekly in 1970 and daily for most of the 1971 irrigation season. The data are too voluminous to include in this report. Samples of the piezometric data which are considered typical of the irrigation season and of early spring conditions are tabulated in Tables 42 and 43 of Appendix C.

Field locations are specified with a number, a letter, a number, a dash (or letter, N), and a number in sequence. The first number designates a drain, the letter denotes the direction from the drain (E, east; or W, west), the next number gives the distance from the drain, the dash means south of the north boundary fence of the farm, and the last number denotes the distance of the piezometer set from the fence. If the letter, N, is used instead of the dash, the piezometer set is located north of the fence. For example, "3W20-400" means that the set is 20 feet west of drain 3 and 400 feet south of the north boundary fence; "3W5N4" means that the set is 5 feet west of drain 3 and 4 feet north of the fence.

Analysis of the piezometric data indicates that there is no upward leakage of water in the saturated zone; i.e., no artesian pressure exists. The general movement of groundwater is from west to east with a slight southerly component which is most noticeable when the farm immediately to the north is being irrigated.

## Soil Samples

During the 1971 season, the soil was sampled on 3 dates in 1-foot increments to a depth of 6 feet at six locations in irrigation blocks 3, 4, 5, 6, 7, 8, and 9. The samples were analyzed for moisture content and EC of soil moisture. A summary of the analyses is given in Table 44 of Appendix C. Typical composition of salts in the Hullinger farm soils is given in Table 45 of Appendix C.

## Groundwater Samples

Typical composition of the groundwater as determined from samples taken from the observation holes is given in Table 46 of Appendix C. EC measurements made in the field on water samples taken from the observation holes are given in Table 47 of Appendix C.

Samples of water were extracted from the saturated zone at 6, 9, and 12 foot depths through pumping the piezometers. This was primarily a test to see if the piezometers could serve a dual purpose, i.e., to provide a site for both piezometric and water quality data. Because of mud flow into and up the piezometer pipe it was determined that the open piezometer pipe, while good for piezometric data, would not serve as a water sampling structure. A ceramic cup should be used for extracting groundwater samples from the soils. Results are given in Table 48 of Appendix C. Sampling was begun within a day after flushing the pipes with city water. Hence, the quality changes reported are probably not representative of the groundwater for the first few samples.

### Hydraulic Conductivity Measurements

In September, 1970, field measurements (Jamil, 1971) were made of the hydraulic conductivity of soils on the Hullinger farm using the auger-hole method and a ditch test developed by Jenab (1967). The nominclature for location of the auger hole tests is the same as used to describe piezometer locations. The auger hole tests were conducted in stages. The first stage measured the hydraulic conductivity (K) from the water table (about four feet) to about eight feet below ground surface. The second stage gave K at depths between 8 and 11 feet. Results are given in Tables 49 and 50 of Appendix C.

### Field Experiment for Detailed Salt Model

The field experiment was conducted on the Hullinger farm. The soil type was Mesa sandy loam. Tensiometer cups were installed in the center of the plot at 15, 45, 75, 105, and 165 cm depth at site A (3E95-380) and 15, 45, 75, 135, and 165 cm depths at site B (3E50-370). To facilitate the collection of reasonable amounts of soil solution for electrical conductivity (EC) measurements, suction was applied on the solution cups for 8 to 12 hours depending upon the moisture content of the soil. Soil samples were collected for chemical analyses at three different times during the experiment. Samples were taken at 30 cm intervals to a depth of 120 cm. Alfalfa was the major crop grown. Sprinklers were used as a means of irrigation. $CaCl_2 \cdot 2H_2O$ (4390.4 kg/ha) and NaCl (3561.6 kg/ha) were applied in dry form to the soil surface before the first and second irrigation cycles. Initial and boundary conditions to the above experiment are given in Tables 5 and 6, respectively. Chemical composition of irrigation water is reported in Table 7. Soil moisture distribution was determined by the neutron probe and water loss by evapotranspiration was estimated from the lysimeter data.

## Laboratory Experiments and Data

### Detailed Salt Model Column Studies

The laboratory experiment was conducted using a lucite column packed with air dry soil obtained from the Hullinger farm. The column consisted of 12 stacked rings with an inner diameter of 10.4 cm and an outer diameter of 11.4 cm. The top ring was 8.5 cm high, whereas

Table 5. Initial conditions for field experiments.

| Depth | Water Content | Calcium | Magnesium | Sodium | Sulfate | Chloride | Bicarbonate | Gypsum |
|---|---|---|---|---|---|---|---|---|
| (cm) | (θ) | (meq/l) | (meq/l) | (meq/l) | (meq/l) | (meq/l) | (meq/l) | (gm/100 gm) |
| 0 - 30 | 0.2347 | 36.0 | 14.31 | 5.04 | 44.25 | 10.35 | 0.75 | 0.0 |
| 30 - 55 | 0.2446 | 25.75 | 14.19 | 4.22 | 34.08 | 9.16 | 0.92 | 0.5 |
| 55 - 100 | 0.2764 | 27.25 | 16.29 | 7.13 | 44.05 | 5.67 | 0.95 | 0.5 |
| 100 - 115 | 0.3053 | 35.10 | 19.95 | 4.91 | 57.84 | 1.30 | 0.82 | 0.5 |
| 115 - 165 | 0.3661 | 32.0 | 16.25 | 4.39 | 50.54 | 1.26 | 0.83 | 0.5 |

Table 6. Boundary condition in the field experiment for soil water and salt flow. Started August 17, 1971.

| Time Interval (hrs) | Flux at the Surface (cm/hr) | ET Flux (cm/hr) | Comment |
|---|---|---|---|
| 0 - 24 | $-0.300(10^{-2})$ | $-0.300(10^{-1})$ | |
| 24 - 40 | 0.64 | 0.0 | Irrigation |
| 40 - 48 | 0.0 | 0.0 | |
| 48 - 72 | $-0.211(10^{-2})$ | $-0.211(10^{-1})$ | |
| 72 - 192 | $-0.187(10^{-2})$ | $-0.187(10^{-1})$ | |
| 192 - 264 | $-0.135(10^{-2})$ | $-0.135(10^{-1})$ | |
| 264 - 324 | $-0.219(10^{-2})$ | $-0.219(10^{-1})$ | |
| 324 - 339 | 0.62 | 0.0 | Irrigation |
| 339 - 408 | $-0.224(10^{-2})$ | $-0.224(10^{-1})$ | |
| 408 - 410 | 0.37 | 0.0 | Rain |
| 410 - 480 | $-0.190(10^{-2})$ | $-0.190(10^{-1})$ | |
| 480 - 504 | 0.0021 | 0.0 | Rain |
| 504 - 528 | $-0.226(10^{-2})$ | $-0.226(10^{-1})$ | |
| 528 - 552 | 0.05 | 0.0 | Rain |
| 552 - 576 | $-0.227(10^{-2})$ | $-0.227(10^{-1})$ | |
| 576 - 600 | $-0.198(10^{-2})$ | $-0.198(10^{-1})$ | |
| 600 - 627 | $-0.191(10^{-2})$ | $-0.191(10^{-1})$ | |

Table 7. Chemical composition of irrigation water.

| | | |
|---|---|---|
| EC | 864 | µmho/cm at 25°C |
| $Ca^{++}$ | 3.16 | meq/l |
| $Mg^{++}$ | 3.88 | meq/l |
| $Na^{+}$ | 1.6 | meq/l |
| $Cl^{-}$ | 0.17 | meq/l |
| $HCO_3^{-}$ | 0.17 | meq/l |
| $SO_4^{--}$ | 8.3 | meq/l |
| $CaSO_4$ ion-pair | 0.84 | meq/l |
| $MgSO_4$ ion-pair | 1.02 | meq/l |

the other 11 rings were 5.1 cm high. The rings were interlocked by a groove and projection arrangement coated with petroleum gel to prevent leakage of water from the column. The whole column was bolted together by three brass rods. The bottom ring had a plate at the bottom with an outlet at its center to collect the effluent. To avoid sealing the outlet with soil, it was covered with a screen and a filter paper.

In order to avoid layering of soil in the column while packing, the following procedure was adopted: Two sieves of 4 mm and 2 mm size were placed one above the other at the top of the column. Air dried, sieved soil is passed through the 4 mm and then onto the 2 mm sieve at such a rate that sieves were not blocked. The column was filled to a height of about 61 cm. The soil was leveled at the surface by hand. The uniformity in the packing was checked with the density probe. If the density of any part of the column was not within ± 0.05 $gm/cm^{-3}$ of the mean density, the column was repacked. (Davidson et al., 1963).

Three different cases of initial and boundary conditions were considered:

Case #1. "Sprinkler irrigation" condition with a layer of salt at the soil surface. $CaCl_2 \cdot 2H_2O$ salt was applied at the rate of (4547.2 kg/ha) before wetting with the irrigation water. The soil was tested by simulated sprinkler irrigation using a constant flow pump at a rate of 0.57 cm/hr. The soil was leached until the wetting front nearly reached the bottom of the column (35.6 hrs.). The column was then segmented. Each segment was weighed to estimate the bulk density. Portions of the soil from each segment were used to extract soil solution and to determine the water content. Exchangeable cations were determined from the other portion of the soil left in each segment. The chemical composition of irrigation water and soil is reported in Tables 7 and 8, respectively.

Table 8. Initial soil conditions for column experiments.

| | Case #1 | Case #2 and #3 |
|---|---|---|
| Calcium (meq/l) | 15.83 | 15.0 |
| Magnesium (meq/l) | 11.31 | 9.87 |
| Sodium (meq/l) | 1.67 | 1.49 |
| Sulfate (meq/l) | 26.80 | 24.78 |
| Chloride (meq/l) | 0.75 | 0.30 |
| Bicarbonate (meq/l) | 1.26 | 1.28 |
| Exchange capacity (meq/100 gm) | 11.0 | 14.0 |
| Gypsum (gm/100 gm) | 0.0 | 0.5 |
| Water content (fraction) | 0.0175 | 0.0175 |

Case #2. "Irrigation" with a layer of salt at the soil surface. The salts applied were $CaCl_2 \cdot 2H_2O$ (1993.6 kg/ha), $MgCl_2 \cdot 6H_2O$ (3225.6 kg/ha), and NaCl (1523.6 kg/ha). The chemical composition of the soil used in this case is given in Table 8. The soil was wetted with distilled water by simulated rain (0.58 cm/hr) for 37.6 hours at which time the wetting front was nearly at the bottom of the column. The column was then segmented and analyzed by the same procedure as in case #1.

Case #3. "Irrigation-evaporation-irrigation" with a layer of salt at each irrigation. Before wetting, $CaCl_2 \cdot 2H_2O$ salt was applied at the rate of 4547.2 kg/ha. The soil was wetted for 35.4 hours by simulated sprinkler irrigation (0.59 cm/hr). The same soil was used as in case #2.

The irrigation water applied had the same composition as in case #1. A water table was created at the end of infiltration and evaporation at the rate of 0.095 $cm/hr^{-1}$ was allowed for 75.8 hours. The chemical composition of the imposed water table was the same as that in the irrigation water. Evaporation at a rate of 0.030 $cm/hr^{-1}$ was then continued without a water table and with the bottom outlet plugged for another 196.8 hours. At the end of evaporation, the soil was wetted by simulated irrigation (0.78 cm/hr for 23.7 hours) with a layer of salt at the soil surface. The salt applied was NaCl (3427.2 kg/ha). During infiltration the bottom outlet was unplugged. At the end of the last irrigation, the column was segmented and analyzed by the same procedure as in cases #1 and #2.

Physical Properties of the Soil. In order to test the applicability of the computer model it is required to have appropriate data of the hydraulic properties of the soil. These properties are hydraulic conductivity-water content (Figure 4) and pressure head-water content (Figure 5) relationships. The data reported by Andrade (1971) for Mesa sandy loam was used in this study.

Chemical Analysis. Electrical conductivity of the soil solution was measured with a Beckman Model RC-19 conductivity bridge using a 2 ml pipet cell with a cell constant of one. Measurements were taken at room temperature and corrected to 25° C.

Chloride concentration was determined potentiometrically using a silver billet electrode and a saturated calomel reference electrode in conjunction with a Corning Model 12 expanded scale pH meter.

The solution extract was diluted with lanthanum oxide in concentrated HCl and the concentration of calcium, magnesium, and sodium was analyzed by atomic adsorption spectophotometer (Perkin-Elmer Model 303).

Bicarbonate ion concentration in the irrigation water was calculated using the relationship

$$H_2O + CO_2 \overset{K}{\rightleftarrows} H^+ + HCO_3^- \qquad [109]$$

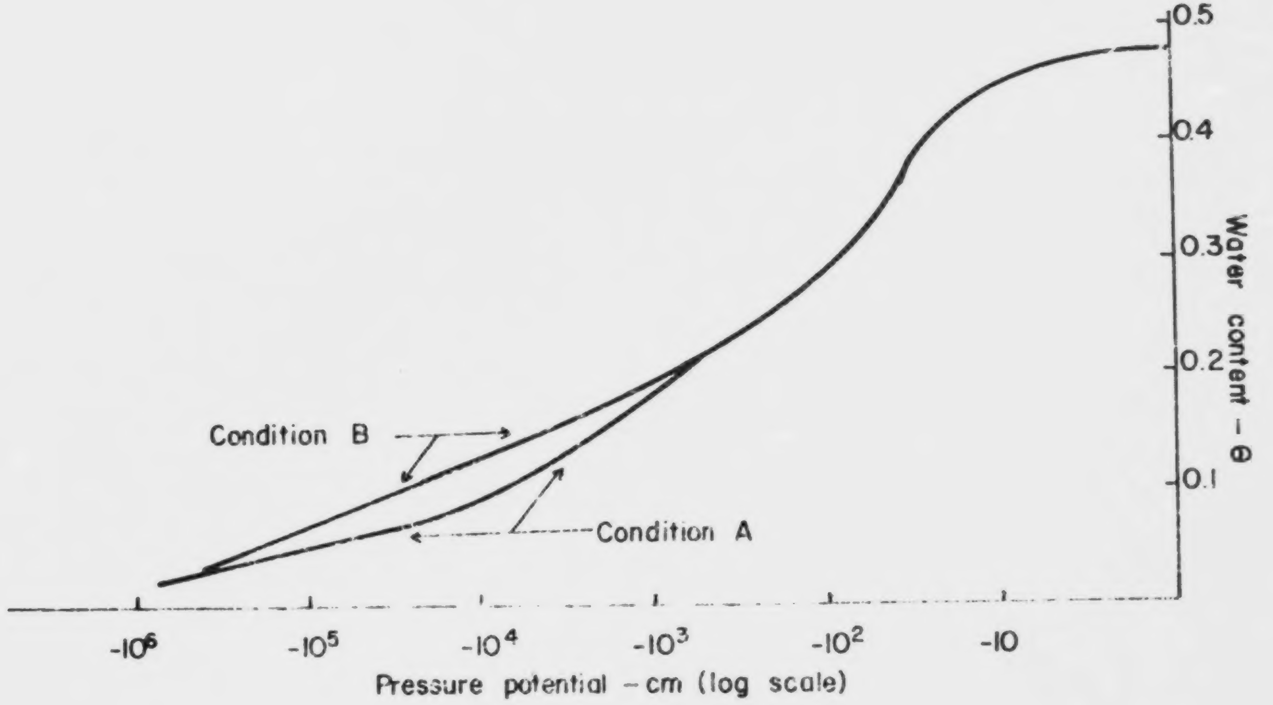

Figure 4. Pressure potential vs water content for Mesa sandy loam soil. Condition A was used in the computation. Condition B was used to test the sensitivity of the model.

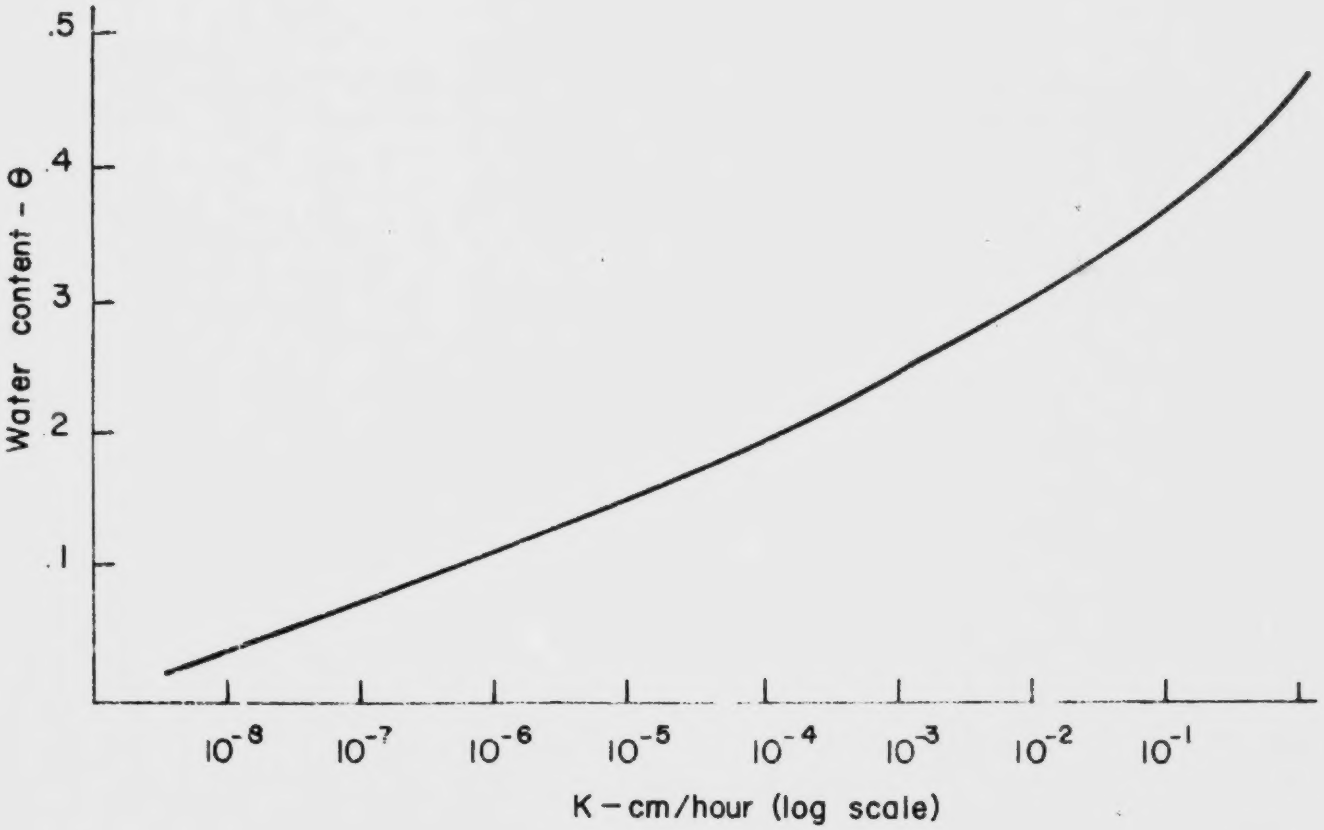

Figure 5. Water content vs hydraulic conductivity for Mesa sandy loam soil.

$$K = \frac{a_H \, a_{HCO_3}}{cP_{CO_2}} \qquad [110]$$

where a is the activity of the ions designated, $a = m\gamma$, m is the molality and $\gamma$ is the activity coefficient. At the reference state $\gamma_{CO_2} = a_{H_2O} = 1$ in pure water. Thus $\gamma_{CO_2}$ can be replaced by $m_{CO_2} = cP_{CO_2}$, where c is Henry's law constant (0.0344 at 25°C), $P_{CO_2}$ is the partial pressure of $CO_2$ in atmospheres $(3 \times 10^{-4})$ and $K = 4.45\,(10^{-7})$.

Bicarbonate ion concentration in the soil solution was estimated from the relationship given by Equation [64] and

$$HCO_3 \overset{K}{\rightleftarrows} H^+ + CO_3^{--} \qquad [111]$$

$$K = \frac{a_H \, a_{CO_3}}{a_{HCO_3}} \qquad [112]$$

where $K = 4.69\,(10^{-11})$. Details of this method are given by Olsen and Watanabe (1959). These concentrations were just an approximation and were corrected by subroutine EXCH to bring them into equilibrium with the system.

The concentration of sulfate ions was estimated from the difference of total anions and the summation of chloride and bicarbonate ions.

For the analysis of exchangeable cations (Richards, 1954), 5 to 7 gms of wet soil sample was washed with 150 ml of 95 percent ethanol in a leaching funnel until free of chloride. Exchangeable calcium and magnesium were extracted by leaching with 100 ml of 1N sodium acetate at pH 8.2. A similar procedure was followed for exchangeable sodium except that it was extracted with 1N ammonium acetate (pH 7.0). Analysis of cations was made as described previously.

Because of the insufficient amount of solution collected in the field experiments for chemical analysis, soil samples were collected and saturation paste prepared (Richards, 1954). The saturation extracts were analyzed as described previously.

Exchange Constant. Exchange constants are defined by Equations [51] and [57]. Their values were determined from the known concentrations of ions in the solution and exchangeable phase. Although their name implies a constant value, they vary with the total salt concentration in the present system. It would be more appropriate to define them as exchange coefficient rather than exchange constant. Figures 6 and 7 are the plots of these coefficients with total salt concentration. Exchange coefficients for case #1 are given by Figures 6a and 7a, while for cases #2 and #3, their values are given in Figures 6b and 7b, respectively.

## Leaching Factor

The leaching factor, LF, is defined by Equation [27] as the mass of salt leaving a layer of soil divided by the sum of the initial mass of salt in the layer and the mass of salt entering the layer. Rasheed (1970) reasoned that LF should depend upon the following dimensionless ratios:

| | |
|---|---|
| Moisture content ratio, | $\theta_o/\theta_{fm}$ |
| Concentration ratio, | $C_o/C_e$ |
| Effluent ratio, | $d_1/d_{fm}$ |

Experimental Equipment. A laboratory experiment was designed to determine the leaching factor for 6-inch layers of Mesa sandy loam. The equipment consisted of three parts or units: the application unit; the container unit; and the collection unit.

The application unit consisted of a water reservoir, a connecting tube, a constant head regulator, a swivel union, a rotating plastic disk, and capillary tubes. The water reservoir (one gallon capacity) was connected to the swivel union by a flexible tube (I. D. 0.25 inches) that passed through the pressure head regulator. The swivel union was connected to a shaft that delivered water to the capillary tubes and rotated the circular disk. The rotating disk was provided with 35 polyethelene capillary tubes that were connected to the disk in a manner that assured uniform application of water to the soil samples. The plastic disk was rotated at a rate of 2 rpm by a small motor through a

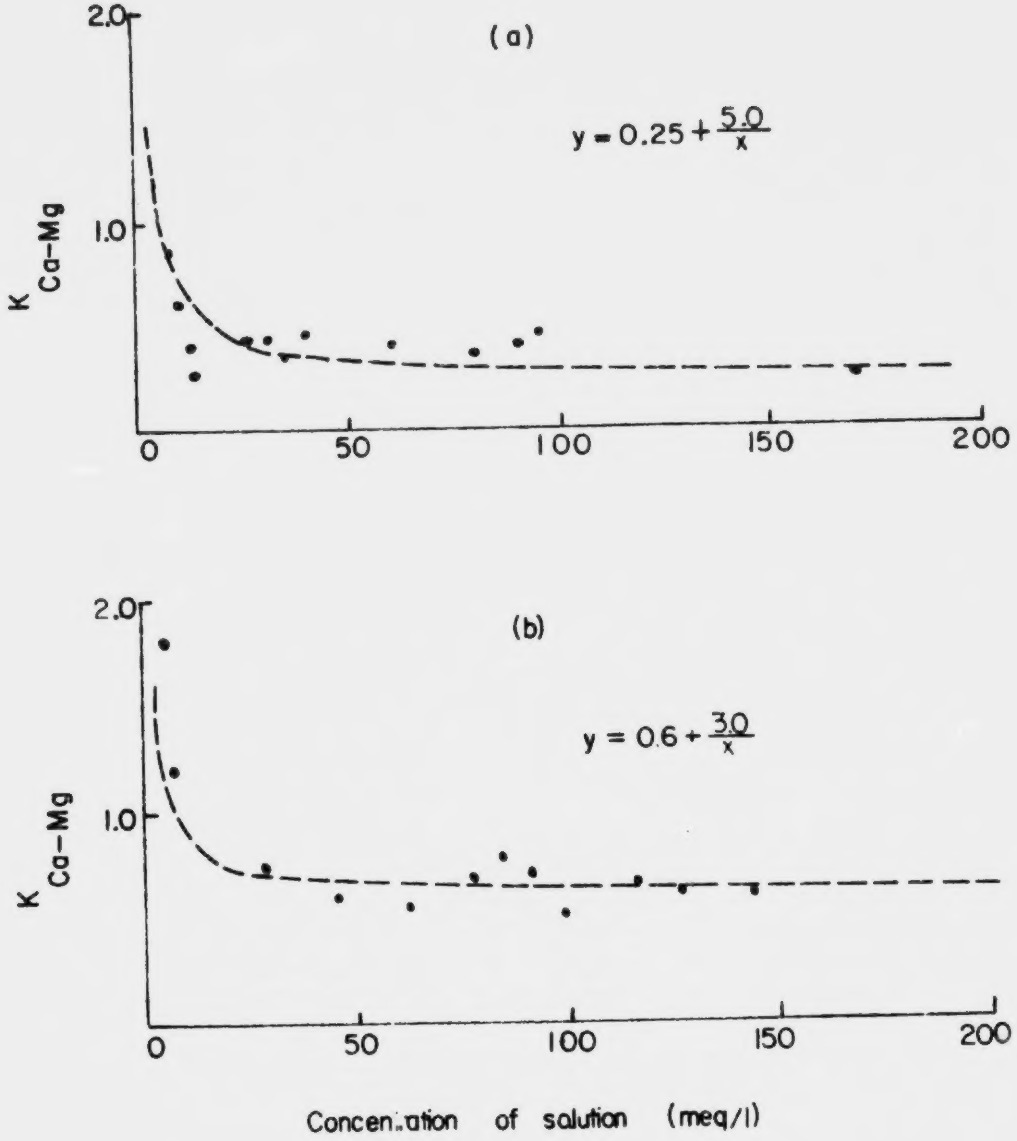

Figure 6. Variation of Ca-Mg exchange coefficient with solution concentration (a) surface soil, (b) subsoil.

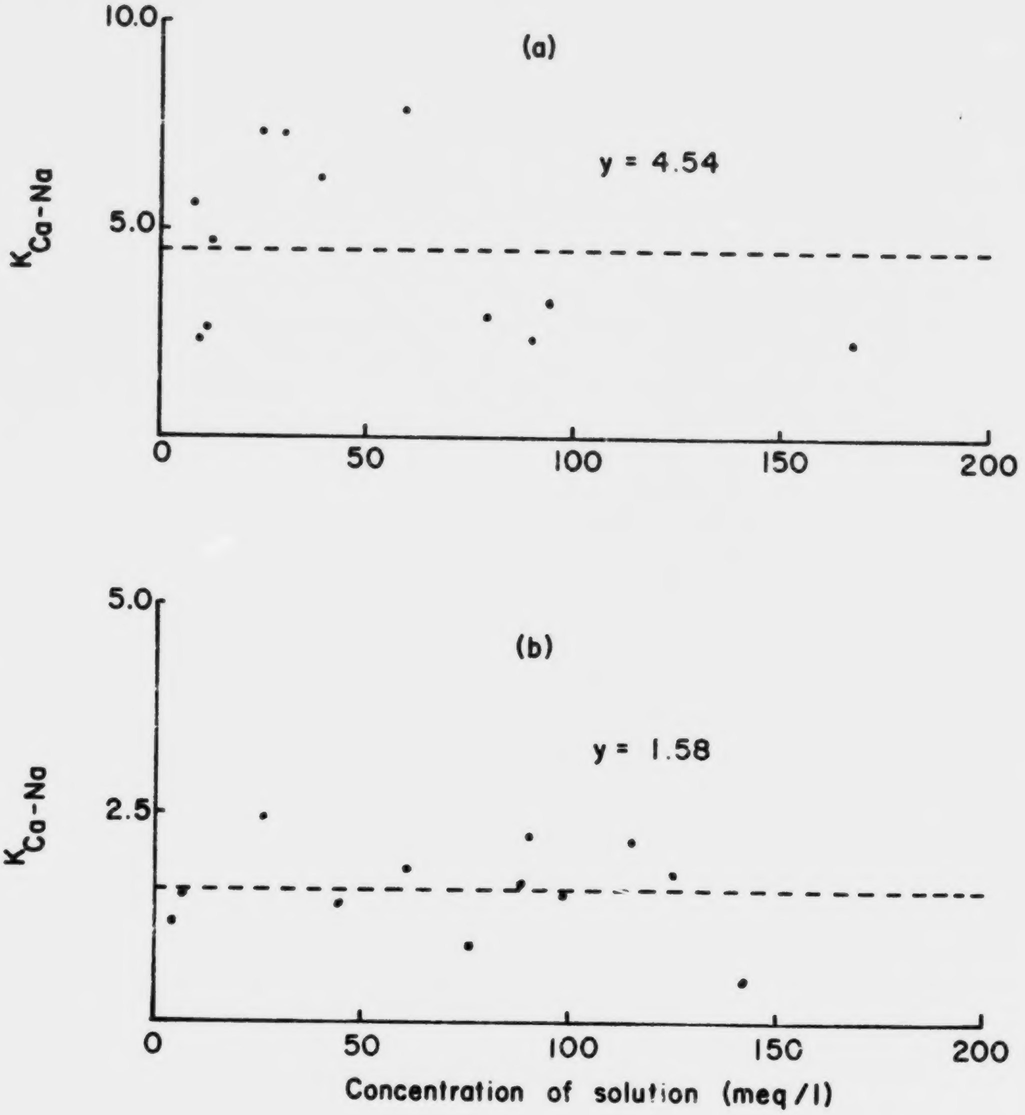

Figure 7. Variation of Ca-Na exchange coefficient with solution concentration (a) surface soil, (b) subsoil.

pulley attached to the connecting shaft. The application rate of the apparatus was calibrated prior to the experimentation.

The container unit consisted of a plastic cylinder, a porous plate and a rigid effluent tube. The base of the cylinder (7.0 inches high and I. D. 5.7 inches ) was fitted with a glass bead porous plate after a circular ridge had been cut in the bottom of the cylinder. A small space was provided between the porous plate and the base of the container and was vented by a rigid plastic tube to provide an outlet for fluid leaving the sample.

The collection unit consisted of a flask, a graduated cylinder, a vacuum pump, and a mercury manometer. The graduated cylinder was connected to the outlet of the sample container by a flexible plastic tube. The flask was connected between the graduated cylinder and the suction line of the pump with the same type of tubing. The mercury manometer was also connected to the suction line.

Experimental Procedure. Bulk soil samples were obtained from two separate locations on the Hullinger farm. The samples were thoroughly mixed and sieved through a 2 mm metal sieve and stored in plastic bags in the laboratory. The average initial salt content in the soil samples was determined according to the procedure recommended by Richards (1954); i.e., measurement of the electrical conductivity of saturation extracts.

Soil samples with a specific salt and water content were prepared by adding calculated amounts of water and salt to the soil as prepared above. The quantities of water and salt required to bring the salt and water content of each subsample to a specific level were mixed (distilled water and salt, NaCl) and a solution was obtained. The soil samples were sprayed with the prepared solutions while being rotated in a small electric mixer. Irrigation water of the specified concentration was prepared in the one gallon water reservoir by adding predetermined amounts of salt (NaCl) to distilled water.

Prepared samples with known salt and water contents were placed in the sample containers in one-half inch layers and compacted to a bulk density of 1.36 ± 0.06 $gm/cm^3$ with a special device (0.5 inch thick plastic disk, 5.0 inch diameter, 9.0 inch long handle). This process continued until the 6.0 inch thick samples were prepared. The containers with the samples were placed under the rotating applicator disks and specific amounts of irrigation water from the reservoir with known concentrations were applied. Water collected under a suction of one-third atmosphere was removed at specified intervals to measure effluent conductivity.

The amount of salt entering any sample was determined from the depth and concentration of water applied. The amount of salt leaving the sample was calculated from the depth of water collected and its concentration. The leaching factor was then determined from Equation [27].

Experimental Results. Leaching factors for various effluent ratios were determined for the soil samples under different initial moisture content and concentration ratios. Samples were prepared according to the procedure outlined previously. Initial moisture content levels of 0.20, 0.15, and 0.05 were investigated with varying concentration ratios.

Soil samples with an initial moisture content (volumetric) of 0.20 were prepared in 6.0 inch layers. Irrigation water concentrations, $C_e$, of 1.00 and 2.00 mmho/cm were prepared in one gallon water reservoirs. Soil water concentrations, $C_o$, of 3.00, 4.00 and 6.00 mmho/cm were obtained by adding precise amounts of salt (NaCl) to the soil samples. Four different experiments were conducted with varying concentration ratios as shown in Table 9.

Table 9. Concentrations (EC in mmho/cm) used to determine LF.

| Experiment | $C_e$ | $C_o$ | $C_o/C_e$ |
|---|---|---|---|
| A | 2.00 | 3.00 | 1.50 |
| B | 2.00 | 4.00 | 2.00 |
| C | 2.00 | 6.00 | 3.00 |
| D | 1.00 | 4.00 | 4.00 |

Leaching factors were determined for various effluent ratios using Equation [27] from the depth and concentration of water entering and leaving the soil sample, as well as the concentration and amount of water in the soil sample. The results are summarized in Table 10.

Table 10. Leaching factor for various effluent ratios (Mesa sandy loam, 6.0 inch samples) for initial moisture content of 0.20 (volumetric).

| $d_1/d_{fm}$ | Leaching Factor, (LF) | | | | Average LF |
|---|---|---|---|---|---|
| | A | B | C | D | |
| 0.1 | 0.081 | 0.085 | 0.087 | 0.081 | 0.084 |
| 0.2 | 0.140 | 0.148 | 0.143 | 0.141 | 0.143 |
| 0.3 | 0.223 | 0.201 | 0.188 | 0.196 | 0.195 |
| 0.4 | 0.275 | 0.261 | 0.280 | 0.270 | 0.272 |
| 0.5 | 0.313 | 0.308 | 0.291 | 0.291 | 0.303 |
| 0.6 | 0.365 | 0.347 | 0.302 | 0.348 | 0.353 |
| 0.7 | 0.391 | 0.378 | 0.381 | 0.391 | 0.394 |
| 0.8 | 0.430 | 0.421 | 0.418 | 0.420 | 0.422 |
| 0.9 | 0.467 | 0.452 | 0.458 | 0.461 | 0.462 |
| 1.0 | 0.500 | 0.478 | 0.473 | 0.481 | 0.483 |
| 1.25 | 0.555 | 0.550 | 0.543 | 0.565 | 0.553 |
| 1.50 | 0.590 | 0.610 | 0.603 | 0.622 | 0.606 |
| 1.75 | 0.651 | 0.653 | 0.654 | 0.650 | 0.652 |
| 2.00 | 0.680 | 0.678 | 0.682 | 0.683 | 0.681 |
| 2.25 | 0.702 | 0.713 | 0.715 | 0.721 | 0.713 |
| 2.50 | 0.710 | 0.725 | 0.741 | 0.764 | 0.735 |
| 2.75 | 0.752 | 0.761 | 0.771 | 0.765 | 0.762 |
| 3.00 | 0.750 | 0.771 | 0.793 | 0.791 | 0.776 |

A: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 3.00 mmho/cm
concentration ratio = 1.5

B: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 4.00 mmho/cm
concentration ratio = 2.0

C: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 6.00 mmho/cm
concentration ratio = 3.0

D: The case where $C_e$ = 1.00 mmho/cm, $C_o$ = 4.00 mmho/cm
concentration ratio = 4.0

Soil samples with initial moisture contents (volumetric) of 0.15 and 0.05 were prepared as above in 6.0 inch layers and the same four experiments listed in Table 9 were conducted. The results are summarized in Tables 11 and 12.

The experimental results presented in Tables 10, 11, and 12 giving the leaching factors in terms of dimensionless effluent ratios under varying initial boundary conditions revealed the following:

1. The leaching factor for the same effluent ratios did not change substantially with the same initial moisture content for varying concentration ratios. However, it must be emphasized here that this consistency may only apply to the particular soil samples (6.0 inch layers prepared according to the procedure outlined previously) and the concentration ratio ranges considered.
2. The leaching factor for the same effluent ratios and concentration ratios varied substantially with the initial moisture content. Relatively large differences between the leaching factors were observed with low effluent ratio values and smaller differences were observed for increasing effluent values.
3. The effluent concentrations leaving the soil samples approached the concentrations of the applied water when the effluent ratios approached the value of 3.0. It was also observed that for an effluent ratio of 0.1 or less the concentration leaving was approximately equal to the initial concentration of the soil water.

In Figure 8 data points are shown for the average leaching factor given in Tables 10, 11, and 12 versus the effluent ratio for soil samples with the three different initial moisture contents. The curves in Figure 8 are calculated from the leaching factor function explained in the following. Similar leaching factor curves may be obtained for any other soil by following the procedure outlined above. The slopes and the degree of variation in the leaching factor curves will vary from soil to soil depending upon soil structure, texture, and other pertinent variables. The average values of LF were used in preparation of Table 1. Thus, Table 1 contains the summary of the leaching factor determinations upon which the leaching factor function was developed as a subroutine to the computer programs for the simplified model.

Table 11. Leaching factor for various effluent ratios (Mesa sandy loam, 6.0 inch samples) for initial moisture content of 0.15 (volumetric).

| $d_l/d_{fm}$ | Leaching Factor, (LF) A | B | C | D | Average LF |
|---|---|---|---|---|---|
| 0.1 | 0.115 | 0.128 | 0.109 | 0.118 | 0.118 |
| 0.2 | 0.186 | 0.196 | 0.207 | 0.179 | 0.192 |
| 0.3 | 0.250 | 0.266 | 0.261 | 0.267 | 0.261 |
| 0.4 | 0.311 | 0.317 | 0.301 | 0.319 | 0.312 |
| 0.5 | 0.371 | 0.372 | 0.368 | 0.364 | 0.359 |
| 0.6 | 0.395 | 0.383 | 0.393 | 0.401 | 0.393 |
| 0.7 | 0.442 | 0.440 | 0.439 | 0.442 | 0.441 |
| 0.8 | 0.460 | 0.466 | 0.461 | 0.455 | 0.461 |
| 0.9 | 0.483 | 0.486 | 0.491 | 0.482 | 0.485 |
| 1.0 | 0.517 | 0.522 | 0.522 | 0.515 | 0.519 |
| 1.25 | 0.573 | 0.570 | 0.571 | 0.572 | 0.572 |
| 1.50 | 0.620 | 0.623 | 0.622 | 0.619 | 0.621 |
| 1.75 | 0.661 | 0.665 | 0.660 | 0.661 | 0.662 |
| 2.00 | 0.705 | 0.704 | 0.700 | 0.701 | 0.702 |
| 2.25 | 0.734 | 0.734 | 0.735 | 0.725 | 0.733 |
| 2.50 | 0.755 | 0.758 | 0.756 | 0.759 | 0.757 |
| 2.75 | 0.769 | 0.773 | 0.762 | 0.779 | 0.771 |
| 3.00 | 0.791 | 0.795 | 0.793 | 0.791 | 0.793 |

A: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 3.00 mmho/cm
concentration ratio = 1.5

B: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 4.00 mmho/cm
concentration ratio = 2.0

C: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 6.00 mmho/cm
concentration ratio = 3.0

D: The case where $C_e$ = 1.00 mmho/cm, $C_o$ = 4.00 mmho/cm
concentration ratio = 4.0

Table 12. Leaching factor for various effluent ratios (Mesa sandy loam, 6.0 inch samples) for initial moisture content of 0.05 (volumetric).

| | Leaching Factor, (LF) | | | | Average |
|---|---|---|---|---|---|
| $d_l/d_{fm}$ | A | B | C | D | LF |
| 0.1 | 0.198 | 0.205 | 0.204 | 0.199 | 0.201 |
| 0.2 | 0.276 | 0.272 | 0.274 | 0.277 | 0.275 |
| 0.3 | 0.303 | 0.300 | 0.308 | 0.301 | 0.303 |
| 0.4 | 0.365 | 0.375 | 0.357 | 0.361 | 0.365 |
| 0.5 | 0.411 | 0.413 | 0.407 | 0.416 | 0.412 |
| 0.6 | 0.430 | 0.433 | 0.435 | 0.428 | 0.432 |
| 0.7 | 0.461 | 0.458 | 0.461 | 0.464 | 0.461 |
| 0.8 | 0.494 | 0.499 | 0.487 | 0.496 | 0.495 |
| 0.9 | 0.519 | 0.522 | 0.520 | 0.518 | 0.520 |
| 1.0 | 0.540 | 0.543 | 0.541 | 0.541 | 0.541 |
| 1.25 | 0.587 | 0.582 | 0.581 | 0.596 | 0.586 |
| 1.50 | 0.631 | 0.640 | 0.630 | 0.630 | 0.633 |
| 1.75 | 0.679 | 0.681 | 0.680 | 0.682 | 0.681 |
| 2.00 | 0.723 | 0.715 | 0.725 | 0.712 | 0.719 |
| 2.25 | 0.742 | 0.743 | 0.738 | 0.747 | 0.741 |
| 2.50 | 0.761 | 0.760 | 0.769 | 0.760 | 0.763 |
| 2.75 | 0.788 | 0.791 | 0.782 | 0.787 | 0.787 |
| 3.00 | 0.798 | 0.804 | 0.794 | 0.796 | 0.798 |

A: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 3.00 mmho/cm concentration ratio = 1.5

B: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 4.00 mmho/cm concentration ratio = 2.0

C: The case where $C_e$ = 2.00 mmho/cm, $C_o$ = 6.00 mmho/cm concentration ratio = 3.0

D: The case where $C_e$ = 1.00 mmho/cm, $C_o$ = 4.00 mmho/cm concentration ratio = 4.0

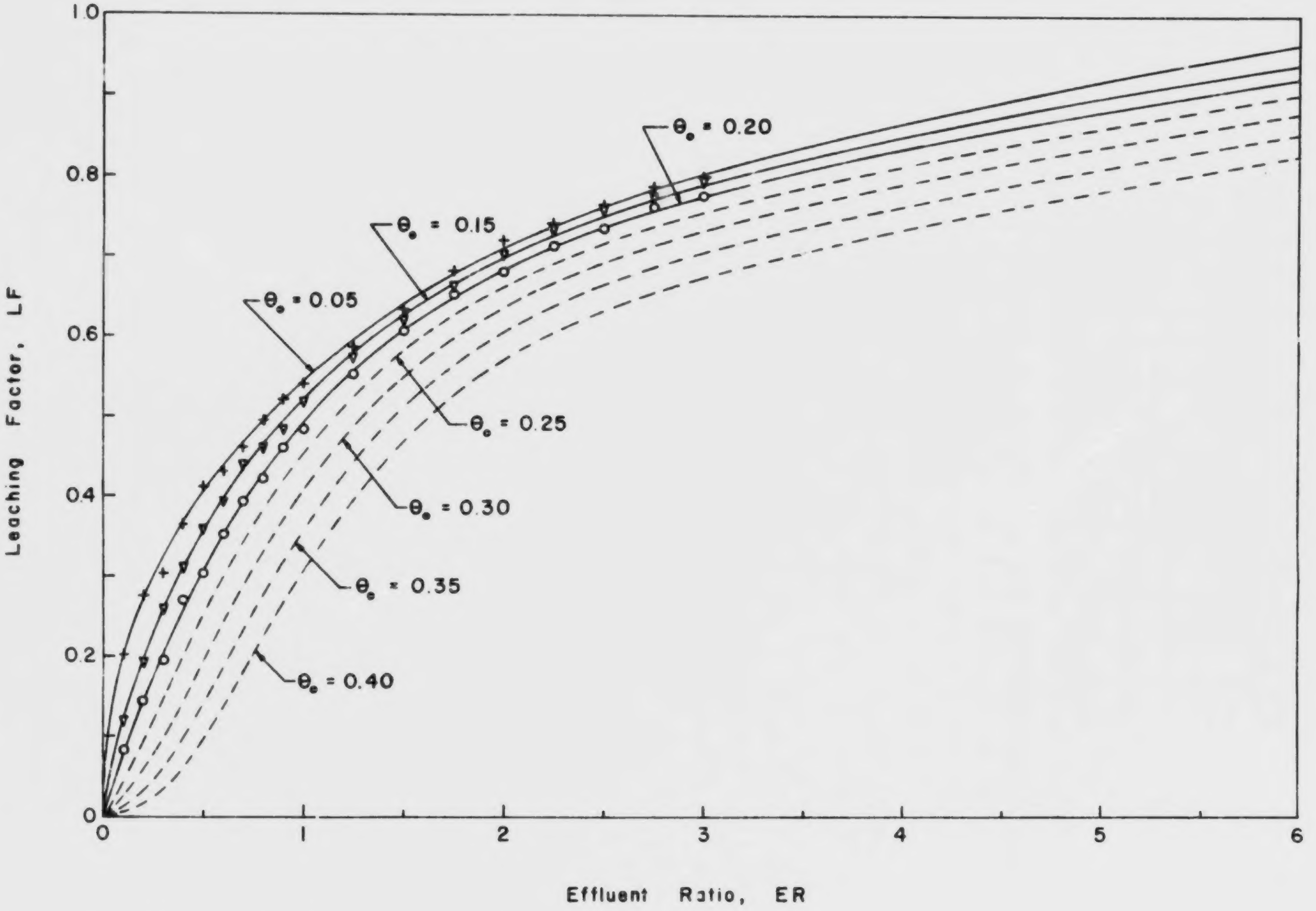

Figure 8. Measured values (points) of leaching factor at three initial moisture contents compared with curves calculated from the leaching factor function.

Leaching Factor Function. In working with the data of Table 1, it was found that a logarithmic plot could be used to produce a family of curves. First, a function of the form

$$\ln y = b_1 + b_2 \ln x + b_3 (\ln x)^2 + b_4 (\ln x)^3 + b_5/x \qquad [113]$$

in which y is the leaching factor (LF) and x is the effluent ratio $(d_1/d_{fm})$, was used to fit the data of Table 1. In order to produce a family of non-intersecting curves slightly different fitting points were used, a total of 20 fitting points were used for each initial moisture content. For $\theta_o = 0.05$, the measured LF at effluent ratios of 0.3, 1.25, and 3.0 were omitted and LF values of 0.854, 0.885, 0.900, 0.905, 0.915 were used for effluent ratios of 4, 5, 6, 7, and 10, respectively. For $\theta_o = 0.15$, all measured data of Table 1 were used as fitting points and in addition LF values of 0.867 and 0.890 were used for effluent ratios of 6 and 10, respectively. For $\theta_o = 0.20$, all measured values were used and LF values of 0.860 and 0.890 for effluent ratios of 6 and 10, respectively, were added.

Each of the coefficients, $b_1$ through $b_5$, inclusive, of Equation [113] may be thought of as functions of $\theta_o$. To complete the family of curves, a parabola of the form

$$b_i = a_{i1} + a_{i2}\theta_o + a_{i3}(\theta_o)^2, \qquad i = 1, 2, \ldots, 5 \qquad [114]$$

was fit through each set of b vs $\theta_o$ data (i = 1, 2, . . ., 5). That is, the coefficients $a_{ij}$ were determined so that Equation [114] passed exactly through each b vs $\theta_o$ point. The resulting 5 by 3 matrix of $a_{ij}$ values is contained in the LF function subroutine (see the FORTRAN listings in Appendix A). For example with i = 1, $b_1$ has the values -0.55492, -0.66130, and -0.86851 for $\theta_o$ equal to 0.05, 0.15, and 0.20, respectively. The final result was a non-intersecting family of curves with $\theta_o$ as a parameter.

In the final family, the curves resulting from Equation [113] were used for effluent ratios in the range, $0.2 < x < 3$. For $x \leq 0.2$ and $x \geq 3$, straight lines on the logarithmic plot were used (Figure 9). The

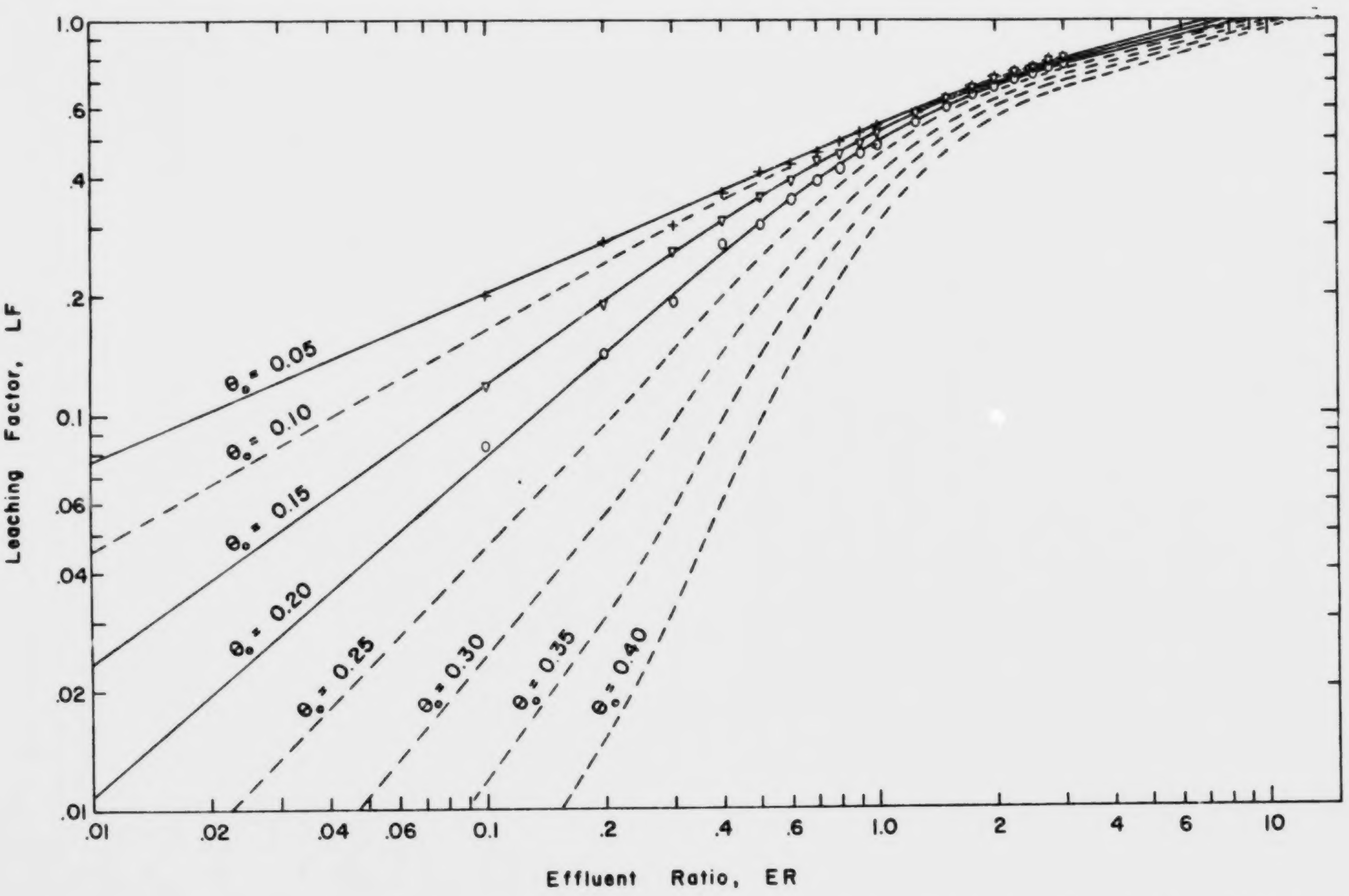

Figure 9. Logarithmic plot of leaching factor vs effluent ratio used to develop the leaching factor function showing measured values (points) compared to curves calculated from the resulting leaching factor function.

equations were

$$y = b_6 x^{b_7} \qquad (x \leq 0.2) \qquad [115]$$

and

$$y = b_8 x^{b_9} \qquad (x \geq 3) \qquad [116]$$

Coefficients, $b_6$ through $b_9$, in Equations [115] and [116] were determined so that the straight lines were tangent to the curves of Equation [113] for each initial moisture content at effluent ratio values of 0.2 and 3.

Details for determining the coefficients $b_6$ through $b_9$ are given as follows: Note that Equation [116] can be written in the form

$$\ln y = \ln b_8 + b_9 \ln x$$

which is the slope intercept form of the straight line on a logarithmic plot. Since $b_9$ is the slope of the straight line, it must equal the slope of Equation [113] at x = 3. The slope of Equation [113] is

$$\frac{d\,(\ln y)}{d\,(\ln x)} = b_2 + 2b_3 \ln x + 3b_4 (\ln x)^2 - b_5/x$$

Thus

$$b_9 = \left.\frac{d\,(\ln y)}{d\,(\ln x)}\right|_{x=3} = b_2 + 2b_3 \ln 3 + 3b_4 (\ln 3)^2 - b_5/3$$

and

$$b_8 = y/3^{b_9}$$

in which y is the value of the leaching factor from Equation [113] for x = 3. In the computer routine, whenever Equation [116] calculated a leaching factor value greater than 1, the leaching factor was set equal to 1.

## Simplified Model

Field data for testing the simplified model were collected during the 1971 irrigation season in which the crop was alfalfa. The evaluation version was used for comparison of computer model calculations with field measurements. In order to use the prediction version, the computer model would have to be run for the entire season to determine an irrigation schedule. Then all field work would have to be conducted according to this schedule. Maintaining a strict schedule in the field would have been difficult. The irrigation water was not available on a strict demand nor was its quality accurately predictable. An accurate forecast of daily evapotranspiration could not be made at the beginning of the season. A reasonable overall schedule of field work was developed, including the irrigation schedules outlined in Tables 3 and 4. Data were collected for testing the simplified model.

### Data and Input Preparation

Because of reseeding the alfalfa in the spring of 1971 rather frequent irrigations were used until the first cutting. On June 22 soil samples were taken and the data furnished the initial conditions for the model. Soil samples were also taken on August 3 and September 9 to compare with calculated results on these dates. The samples were analyzed in the laboratory to determine the moisture content gravimetrically and the electrical conductivity of the saturation extract, $EC_e$ (Table 44, Appendix C).

The moisture content data from the soil samples were not used because they did not appear to be reliable. In order for the moisture content from soil samples to have been the same as determined by the neutron meter, the bulk density of the soil would have to have been as high as 2.0 in some locations. The difference may have been due to the small size of the soil cores and loss of moisture from the samples while they were in storage for several months. Consequently, the volumetric soil moisture content ($\theta$) as determined by the neutron meter on the same days that the soil samples were taken was used in testing the model (Table 13).

Inspection of the $EC_e$ data indicated the probability that no change in salt content of the soil occurred during the season. This was confirmed by statistical analysis of the data for the top one foot of the soil profile (Table 14). Analysis of variance showed no significant differences at

Table 13. Volumetric moisture content (θ) measured by neutron meter on dates of soil sampling.

| | Depth (inches) | Block 3 | Block 5* | Block 6 | Block 7 |
|---|---|---|---|---|---|
| June 22 | 12 | .236 | .200 | .226 | .231 |
| | 18 | .274 | .248 | .298 | .243 |
| | 30 | .273 | .238 | .293 | .289 |
| | 42 | .332 | .274 | .366 | .363 |
| | 54 | .336 | .327 | .411 | .416 |
| | 66 | .409 | .396 | .418 | .409 |
| August 3 | 12 | .303 | .252 | .295 | .242 |
| | 18 | .311 | .276 | .323 | .249 |
| | 30 | .302 | .264 | .346 | .354 |
| | 42 | .320 | .294 | .406 | .396 |
| | 54 | .401 | .385 | .411 | .410 |
| | 66 | | .414 | | |
| September 9 | 12 | .329 | .275 | .299 | .282 |
| | 18 | .324 | .288 | .337 | .290 |
| | 30 | .323 | .280 | .391 | .363 |
| | 42 | .351 | .313 | .400 | .383 |
| | 54 | .414 | .389 | | .406 |
| | 66 | | .411 | | |

* Average of 6 sites

the 10 percent level between the means of $EC_e$ values for the three sampling dates (Table 15). It is probable that analysis of data from any other soil depth increment would yield similar results because of the large differences between values for a given block and sampling time.

Examination of data from the top one foot of soil reveals even more information because it is the only zone that consistently receives the same treatment within a given block; i.e., the same depth and concentration of irrigation water is theoretically applied to all sites within each block. Therefore, when the soil at two sites within a block has the same $EC_e$ value at a given time, the values should also be similar when checked at a later time. Table 14 shows the variation which

Table 14. $EC_e$ of the top one foot of soil at six sites within each irrigation block as determined from soil samples taken on June 22, August 3, and September 9.

| | Site | $EC_e$ (mmho/cm) June 22 | $EC_e$ (mmho/cm) Aug. 3 | $EC_e$ (mmho/cm) Sept. 9 |
|---|---|---|---|---|
| Block 3 | NW | 1.43 | 2.70 | 2.98 |
| | NE | 1.98 | 1.78 | 1.60 |
| | MW | 1.98 | 2.45 | 1.21 |
| | ME | 3.43 | 1.79 | 1.24 |
| | SW | 2.00 | 2.12 | 1.19 |
| | SE | 2.30 | --- | 1.52 |
| Block 5 | NW | 0.99 | 1.43 | 1.20 |
| | NE | 1.25 | 1.34 | 1.44 |
| | MW | 1.45 | 1.33 | 1.24 |
| | ME | 1.84 | 1.53 | 1.65 |
| | SW | 1.66 | 3.41 | 1.73 |
| | SE | 1.63 | 2.79 | 1.00 |
| Block 6 | NW | 2.81 | 2.72 | 2.85 |
| | NE | 1.24 | 2.64 | 4.61 |
| | MW | 3.30 | 2.94 | 1.45 |
| | ME | 5.16 | 2.77 | 1.82 |
| | SW | 0.94 | 1.37 | 4.13 |
| | SE | 3.25 | 3.06 | 3.68 |
| Block 7 | NW | 2.80 | 2.64 | 3.37 |
| | NE | 2.66 | --- | 3.33 |
| | MW | 4.14 | 3.03 | 3.05 |
| | ME | 3.04 | 2.91 | 3.15 |
| | SW | 3.35 | 8.40 | 3.83 |
| | SE | 2.88 | 2.70 | 2.18 |

Table 15. Analysis of variance for $EC_e$ of soil samples from the top one foot of soil taken on June 22, August 3, and September 9.

| | Source of Variation | Degrees of Freedom | Mean Squares | F |
|---|---|---|---|---|
| Block 3 | | | | |
| | Time of sampling | 2 | 0.598 | 0.548* |
| | Experimental error | 14 | 1.091 | |
| | Total | 16 | 1.029 | |
| Block 5 | | | | |
| | Time of sampling | 2 | 0.614 | 1.877* |
| | Experimental error | 15 | 0.327 | |
| | Total | 17 | 0.361 | |
| Block 6 | | | | |
| | Time of sampling | 2 | 0.391 | 0.268* |
| | Experimental error | 15 | 1.460 | |
| | Total | 17 | 1.334 | |
| Block 7 | | | | |
| | Time of sampling | 2 | 1.095 | 0.548* |
| | Experimental error | 14 | 1.998 | |
| | Total | 16 | 1.885 | |

*Not significant at 10 percent level

actually existed at such sites. For example, on June 22 the $EC_e$ at sites Block 3 NE and MW was 1.98 mmho/cm. However, on August 3 the EC had decreased at Block 3 NE to 1.78 mmho/cm, and increased at Block 3 MW to 2.45 mmho/cm. This illustrates the differences that exist between what is expected theoretically and what occurred under this experimental procedure. The reasons for the differences probably include taking samples from slightly different locations at a site, nonhomogeneous soil within blocks, lack of uniformity of irrigation water application, and inaccuracy of the laboratory method for determining $EC_e$.

Although it could not be shown that changes occurred in the salt content of the soil profile during the season, this did not prevent the accomplishment of the objectives of the study. It was assumed that if the model to be evaluated was adequate, it would predict that there would be no significant changes, in accordance with the measured field conditions. Also, regardless of any difficulties that may have existed with respect to the field data representing the salinity status of the soil profile, sufficient information was available to evaluate the ability of the model to predict water movement. This was especially true of Block 5, where there were six access tubes from which moisture content of the soil profile was determined by the neutron probe.

The shortest interval of time used in the simplified model is one day (24 hours). Daily ET during the growing season was obtained by averaging data from two lysimeters (Table 34, Appendix C). The period of measurement for ET was from 8 a.m. of one day until 8 a.m. of the next day. The data of Table 34 are recorded on the date of ending of the 24-hour measurement period. In the simplified model, if irrigation occurs on a given day, the ET of that day is included in the interval following the irrigation. Since the major part of the measured ET occurred during daylight hours, for testing the simplified model, the daily ET was assigned to the date of beginning of the 24-hour measurement period. For example, in testing the simplified model, the ET of 0.84 cm recorded for May 15 in Table 34 was used for May 14, etc.

Electrical conductivity (EC) of irrigation water was usually measured (Tables 16 through 20). Where no measurement was available an estimate was made, based on measurements taken close to the time of that irrigation. The range in measured EC of irrigation water during the season was 0.80 to 1.30 mmho/cm. Rain water was assumed to have an EC of 0.01 mmho/cm. Tables 16 through 20 show the schedule of irrigations as they actually occurred in the field.

Selection of input values of the wilting percentage and recommended maximum $EC_s$ for each soil layer was arbitrary since these values were used only for comparison purposes. A volumetric moisture content of 0.08 (15-bar water content) was assumed for the wilting point of the soil on the experimental farm. Recommended maximum $EC_s$ values were chosen arbitrarily as 4, 5, 6, and 7 mmho/cm for soil layers 1, 2, 3, and 4 respectively. For the deeper layers where there was assumed to be no moisture extraction by plant roots, 100 mmho/cm was input.

Table 16. Irrigation schedule and depth and EC of irrigation water for Block 3 during the evaluation period.

| | Date of Irrigation | Length of Irrigation Interval (days) | Depth Applied (inches) | EC of Irrigation Water (mmho/cm) |
|---|---|---|---|---|
| June 22 # | | | | |
| | | (6*) | | |
| | June 28 | | 3.00 | 1.27 |
| | | 4 | | |
| | July 2 | | 1.00 | 1.29 |
| | | 3 | | |
| | July 5 | | 1.00 | .80 |
| | | 4 | | |
| | July 9 | | 1.00 | .98 |
| | | 3 | | |
| | July 12 | | 1.00 | .86 |
| | | 4 | | |
| | July 16 | | 1.00 | 1.05 |
| | | 4 | | |
| | July 20 | | 1.00 | .94 |
| | | 3 | | |
| | July 23 | | 1.00 | 1.30 |
| | | 4 | | |
| | July 27 | | 1.00 | 1.00 |
| | | (8*) | | |
| Aug. 3 # | | 17 | | |
| | | (9*) | | |
| | Aug. 13 | | 1.25 | 1.20 |
| | | 3 | | |
| | Aug. 16 | | 3.75 | 1.21 |
| | | 14 | | |
| | Aug. 30 | | 5.50 | .86 |
| | | 9 | | |
| | Sept. 8 | | .48** | .01 |
| | | (2*) | | |
| Sept. 9 # | | | | |

# Date of soil sampling

* Days between soil measurements and irrigation

** Rain

Table 17. Irrigation schedule and depth and EC of irrigation water for Block 4 during the evaluation period.

| | Date of Irrigation | Length of Irrigation Interval (days) | Depth Applied (inches) | EC of Irrigation Water (mmho/cm) |
|---|---|---|---|---|
| June 22 # ______ | | | | |
| | | (6*) | | |
| | June 28 | | 3.00 | 1.27 |
| | | 7 | | |
| | July 5 | | 2.00 | .80 |
| | | 7 | | |
| | July 12 | | 2.00 | .86 |
| | | 7 | | |
| | July 19 | | 2.00 | .94 |
| | | 8 | | |
| | July 27 | | 2.00 | 1.00 |
| | | (8*) | | |
| Aug. 3 # ______ | | 18 | | |
| | Aug. 14 | | 4.00 | 1.20 |
| | | 14 | | |
| | Aug. 28 | | 4.00 | .85 |
| | | 11 | | |
| | Sept. 8 | | .48** | .01 |
| | | (2*) | | |
| Sept. 9 # ______ | | | | |

# Date of soil sampling
* Days between soil measurements and irrigation
** Rain

Table 18. Irrigation schedule and depth and EC of irrigation water for Block 5 during the evaluation period.

| | Date of Irrigation | Length of Irrigation Interval (days) | Depth Applied (inches) | EC of Irrigation Water (mmho/cm) |
|---|---|---|---|---|
| June 22 # | | | | |
| | | (7*) | | |
| | June 29 | | 3.00 | 1.27 |
| | | 11 | | |
| | July 10 | | 3.00 | .98 |
| | | 10 | | |
| | July 20 | | 3.00 | 1.53 |
| | | 9 | | |
| | July 29 | | .83 | 1.00 |
| | | (6*) | | |
| Aug. 3 # | | 20 | | |
| | | (14*) | | |
| | Aug. 18 | | 4.00 | .94 |
| | | 12 | | |
| | Aug. 30 | | 3.00 | .86 |
| | | 9 | | |
| | Sept. 8 | | .48** | .01 |
| | | (2*) | | |
| Sept. 9 # | | | | |

# Date of soil sampling
* Days between soil measurements and irrigation
** Rain

Table 19. Irrigation schedule and depth and EC of irrigation water for Block 6 during the evaluation period.

|  | Date of Irrigation | Length of Irrigation Interval (days) | Depth Applied (inches) | EC of Irrigation Water (mmho/cm) |
|---|---|---|---|---|
| June 22 # |  |  |  |  |
|  |  | (8*) |  |  |
|  | June 30 |  | 3.00 | 1.29 |
|  |  | 13 |  |  |
|  | July 13 |  | 3.25 | .86 |
|  |  | 10 |  |  |
|  | July 23 |  | .75 | 1.30 |
|  |  | 5 |  |  |
|  | July 28 |  | 4.00 | 1.00 |
|  |  | (7*) |  |  |
| Aug. 3 # |  | 18 |  |  |
|  |  | (11*) |  |  |
|  | Aug. 15 |  | 2.00 | 1.20 |
|  |  | 9 |  |  |
|  | Aug. 24 |  | 2.00 | .84 |
|  |  | 7 |  |  |
|  | Aug. 31 |  | 2.00 | 1.23 |
|  |  | 10 |  |  |
|  | Sept. 8 |  | .48** | .01 |
|  |  | (2*) |  |  |
| Sept. 9 # |  |  |  |  |

# Date of soil sampling

* Days between soil measurements and irrigation

** Rain

Table 20. Irrigation schedule and depth and EC of irrigation water for Block 7 during the evaluation period.

| | Date of Irrigation | Length of Irrigation Interval (days) | Depth Applied (inches) | EC of Irrigation Water (mmho/cm) |
|---|---|---|---|---|
| June 22 # | ______________ | | | |
| | | (8*) | | |
| | June 30 | | 3.00 | 1.29 |
| | | 7 | | |
| | July 7 | | .50 | .80 |
| | | 11 | | |
| | July 18 | | 5.62 | .94 |
| | | 11 | | |
| | July 29 | | .83 | 1.00 |
| | | (6*) | | |
| Aug. 3 # | ______________ | 17 | | |
| | | (11*) | | |
| | Aug. 15 | | 1.00 | 1.21 |
| | | 3 | | |
| | Aug. 18 | | 1.00 | .94 |
| | | 6 | | |
| | Aug. 24 | | 1.00 | .84 |
| | | 5 | | |
| | Aug. 29 | | 1.00 | .86 |
| | | 3 | | |
| | Sept. 1 | | .75 | 1.23 |
| | | 7 | | |
| | Sept. 8 | | .48** | .01 |
| | | (2*) | | |
| Sept. 9 # | ______________ | | | |

# Date of soil sampling
* Days between soil measurements and irrigation
** Rain

Because the computer program requires the input of the electrical conductivity of the soil solution ($EC_s$), it was necessary to convert the $EC_e$ data to this form. Assuming homogeneous field soils within a given irrigation block, the volumetric moisture content under saturated conditions in the field was estimated from neutron meter readings. The field bulk density was then calculated from the values using the particle density of 2.65 gm/cm$^3$. The bulk density values for irrigation Blocks 3, 5, 6, and 7 were found to be 1.43, 1.56, 1.56, and 1.55, respectively. Using the values of bulk density, the volumetric moisture contents from the neutron meter at the three dates of soil sampling were converted to moisture content by weight, W. Then $EC_s$ was computed from

$$EC_s = \frac{W_e}{W} EC_e$$

where $W_e$ is the moisture content by weight at saturation of the sample used to obtain the extract. The average $EC_e$ and $W_e$ values for each soil layer and irrigation block were used in the calculations. These averages and the corresponding calculated values of $EC_s$ and values of $\theta$, which were used in testing the model are given in Table 44, Appendix C.

Six-inch soil layers were used for testing the model since the laboratory soil samples used to establish the leaching factor function were 6-inches thick. The number of soil layers considered for each irrigation block was determined on the basis of piezometer readings made throughout the period. Determining the average depth to the water table made it possible to consider only the unsaturated zone in the calculations. This permits the calculation of the amount of salt entering the saturated region and increasing the groundwater salt load as well as becoming a potential pollutant to receiving streams.

The root distribution for the alfalfa on the experimental plot was estimated by analyzing soil samples for carbon content. It was concluded that the moisture extraction for 6-inch intervals from the soil surface to a depth of 2 feet was 41%, 30%, 19%, and 10%, respectively.

Moisture content profiles determined from neutron probe readings made at various time intervals after irrigations were used to establish values of $\theta_{fm}$ in each soil layer of each block. Figure 10 illustrates

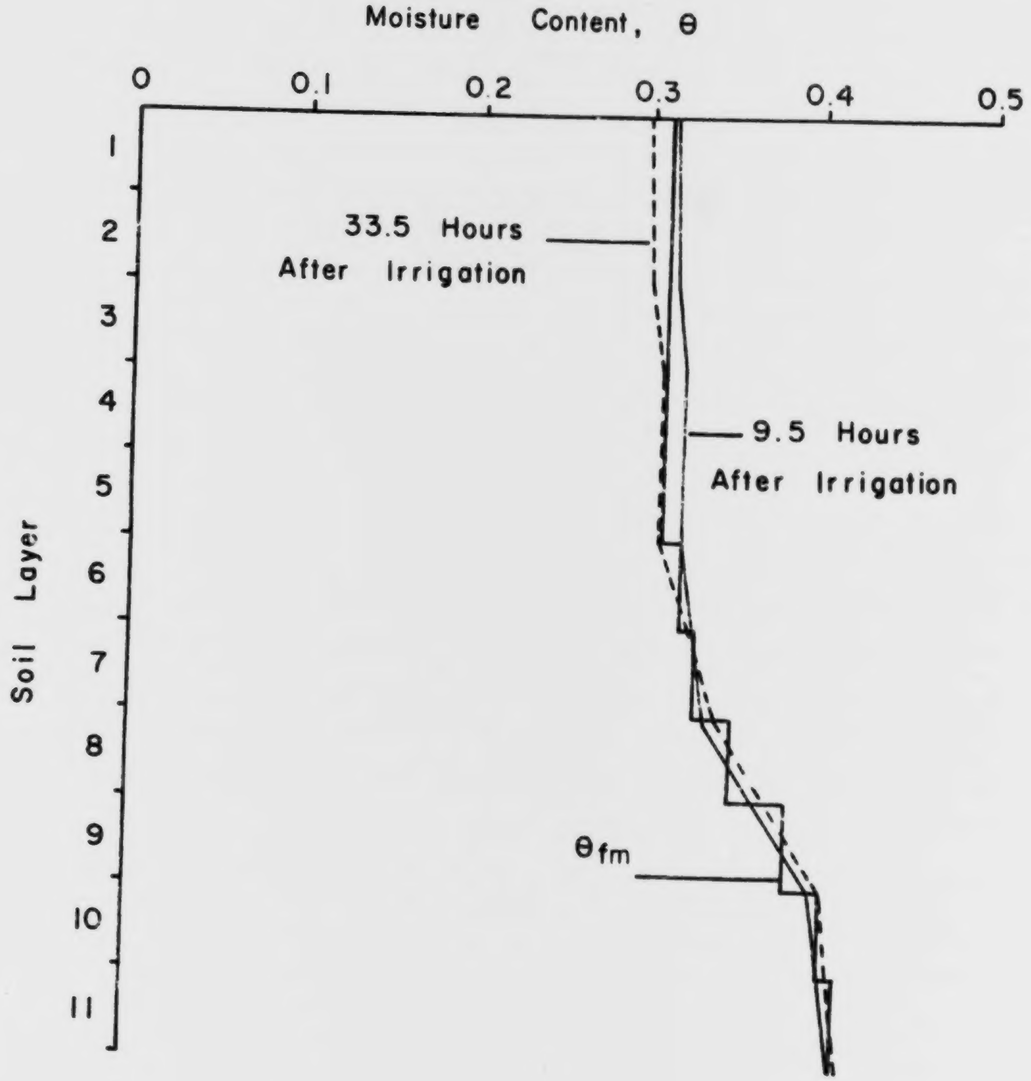

Figure 10. Upper limit of field moisture, $\theta_{fm}$, in each soil layer in Block 5 as determined from moisture content measured 9.5 and 33.5 hours after an irrigation ended (measured values are averaged from 5 locations).

the method used. Moisture content profiles are shown as measured 9.5 and 33.5 hours after an irrigation ended on Block 5. It was assumed that downward drainage had essentially ceased in the upper part of the profile after 33.5 hours, since further moisture loss could be accounted for as ET. Part of the moisture loss in the upper part of the profile was accounted for in the measured ET of 0.20 inch during the 24-hour period between measurements with the neutron probe. The rest of the moisture loss in the upper part of the profile showed up as increase of moisture content in the lower part during the 24-hour period. Even after 33.5 hours, downward drainage appears to be occurring in the lower part of the profile. Root extraction of moisture was determined to be negligible in the lower part of the profile. The moisture content after 9.5 hours was taken as $\theta_{fm}$ for the lower part of the profile since it was considered to be closer to the equilibrium condition. The upper limit of field moisture for the other blocks was determined by the same method but with less extensive data. The values of $\theta_{fm}$ that were used to test the simplified model are shown in Table 21.

Table 21. The upper limit of field moisture ($\theta_{fm}$) for each soil layer and irrigation block.

| Soil Layer | Irrigation Block | | | |
|---|---|---|---|---|
| | 3 | 5 | 6 | 7 |
| 1 | .338 | .311 | .330 | .311 |
| 2 | .338 | .311 | .330 | .311 |
| 3 | .338 | .311 | .330 | .311 |
| 4 | .338 | .311 | .334 | .311 |
| 5 | .338 | .311 | .342 | .342 |
| 6 | .341 | .319 | .360 | .360 |
| 7 | .347 | .330 | .388 | .388 |
| 8 | .365 | .351 | .404 | .404 |
| 9 | .395 | .385 | | |
| 10 | .415 | .406 | | |
| 11 | .425 | .415 | | |

## Model Results

Results obtained by using the simplified model on Blocks 3, 5, 6, and 7 are shown on Figures 11 through 14. The moisture content, $\theta$, and electrical conductivity of the soil solution, $EC_s$, for each soil layer are shown for input values on June 22 and for measured and calculated values at the two checkpoints (August 3 and September 9). The computer output for Block 5 is included in Appendix A as Example 3.

Water Movement. In comparing the predicted and measured moisture contents, it should be kept in mind that the model assumed no moisture extraction by plant roots below the fourth layer. Therefore, once $\theta_{fm}$ or any lesser moisture content was reached below this layer, the moisture content was never less than this value. All layers must reach $\theta_{fm}$ before any water enters the saturated zone.

At only three of the eight checkpoints included in the four blocks were all layers at $\theta_{fm}$. These were for Block 3 (Figure 11 b) and Block 6 (Figures 13 a and 13 b). From the computer output it was found that this condition resulted when only 3 of the 38 irrigations applied on the four blocks resulted in water entering the saturated zone. Two of these occurred between the first and second checkpoints on Block 3 and one was prior to the first checkpoint on Block 6. This does not agree with the drain discharge measurements which indicated continuous flow during the test period from Blocks 6 and 7, and occasional flow from Block 5.

It must therefore be concluded that there was upward movement of water from the saturated zone which the model could not account for. This conclusion is substantiated by Table 22 which gives the depth of water that exists in the unsaturated soil zone which cannot be accounted for by considering only irrigation water applied and evapotranspiration during the study period. In computing values of Table 22, loss of water from the soil profile to the saturated zone was not estimated. If downward drainage was occurring during the periods, then total upward flow would have been greater than calculated. However, net values of upward flow as computed in Table 22 would be correct if the applied irrigation water and ET are correct. A negative value in columns 4 or 5 indicate a net downward movement of water from the soil profile into the saturated zone.

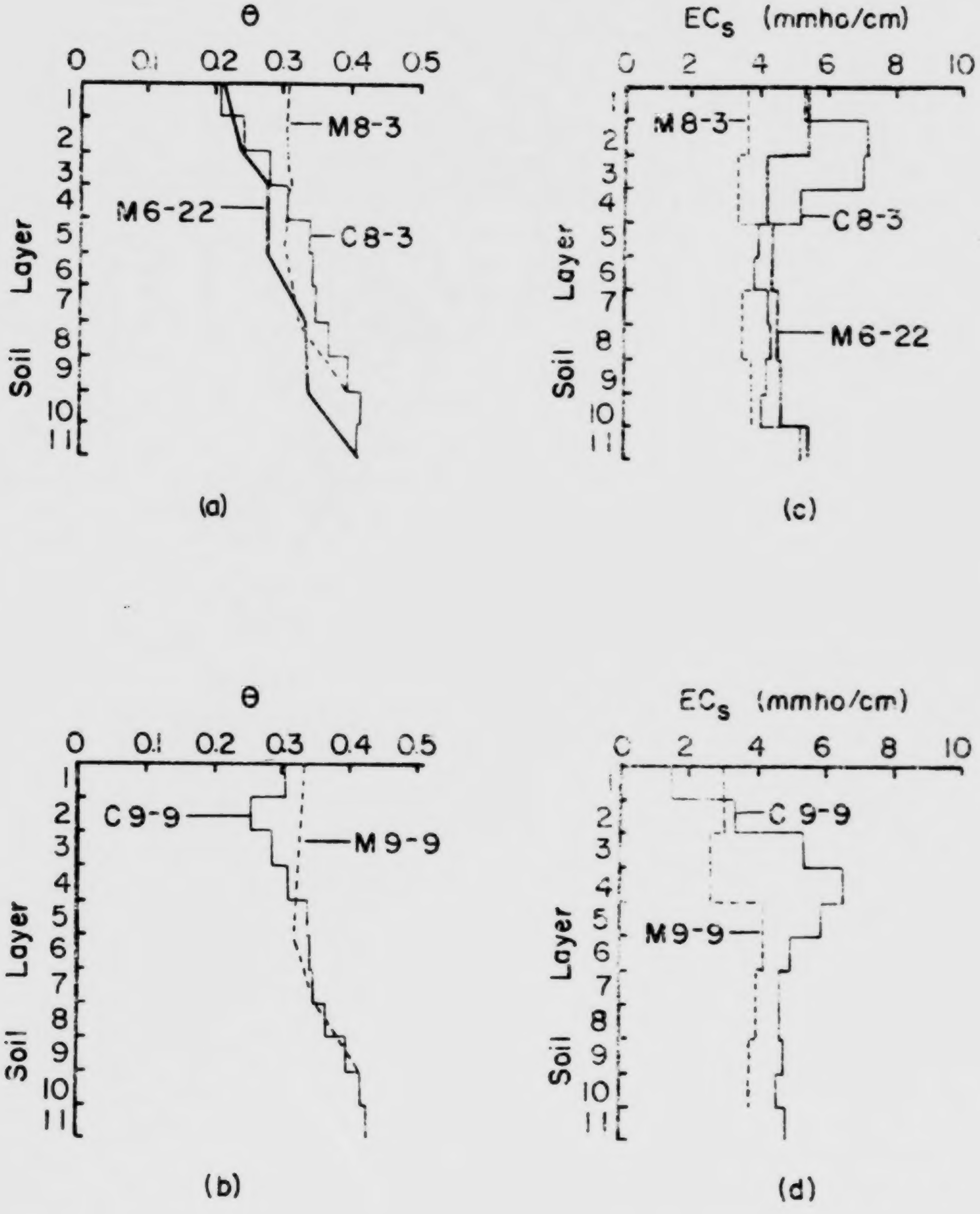

Figure 11. Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, for Block 3.

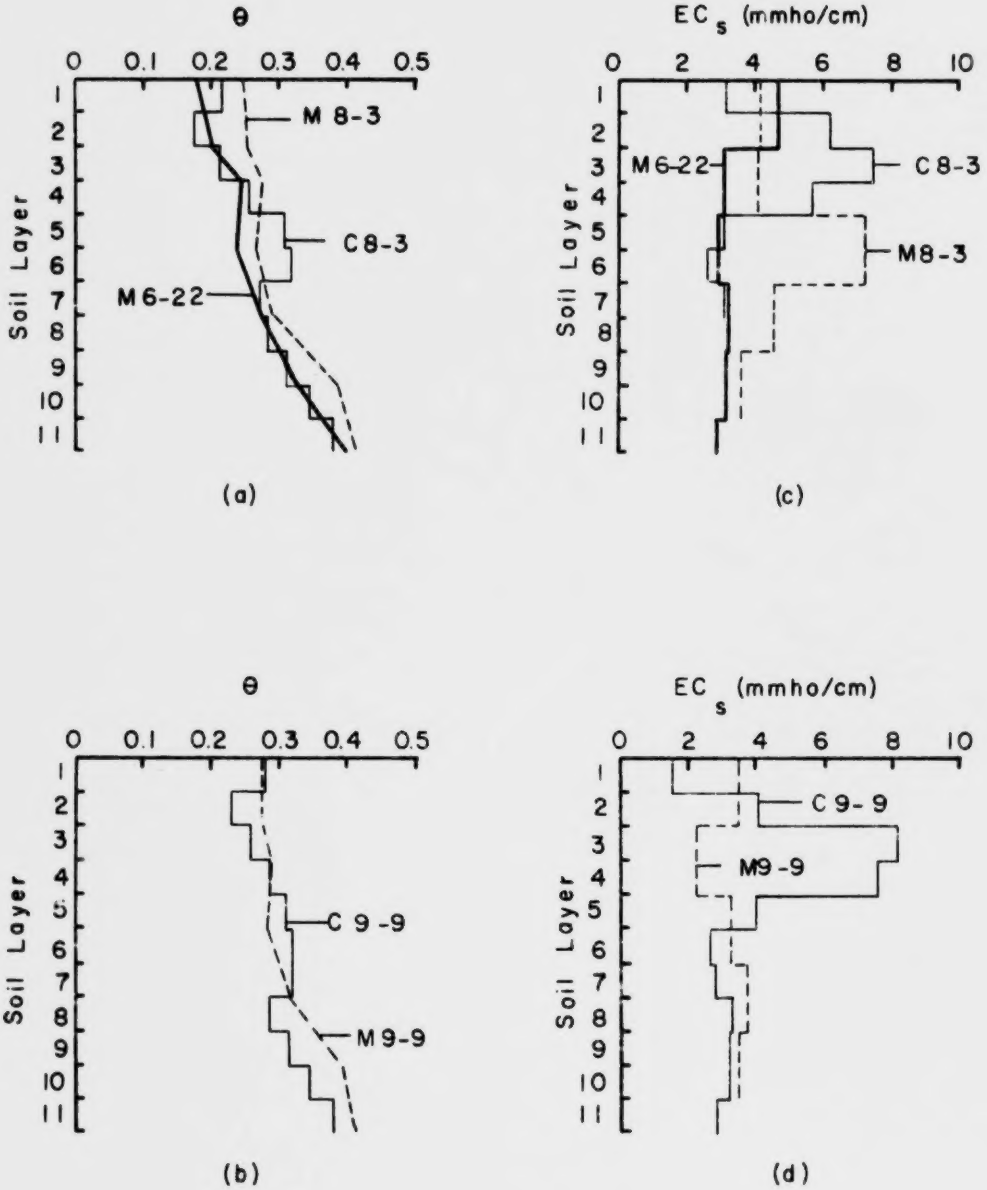

Figure 12. Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, EC$_s$, for Block 5.

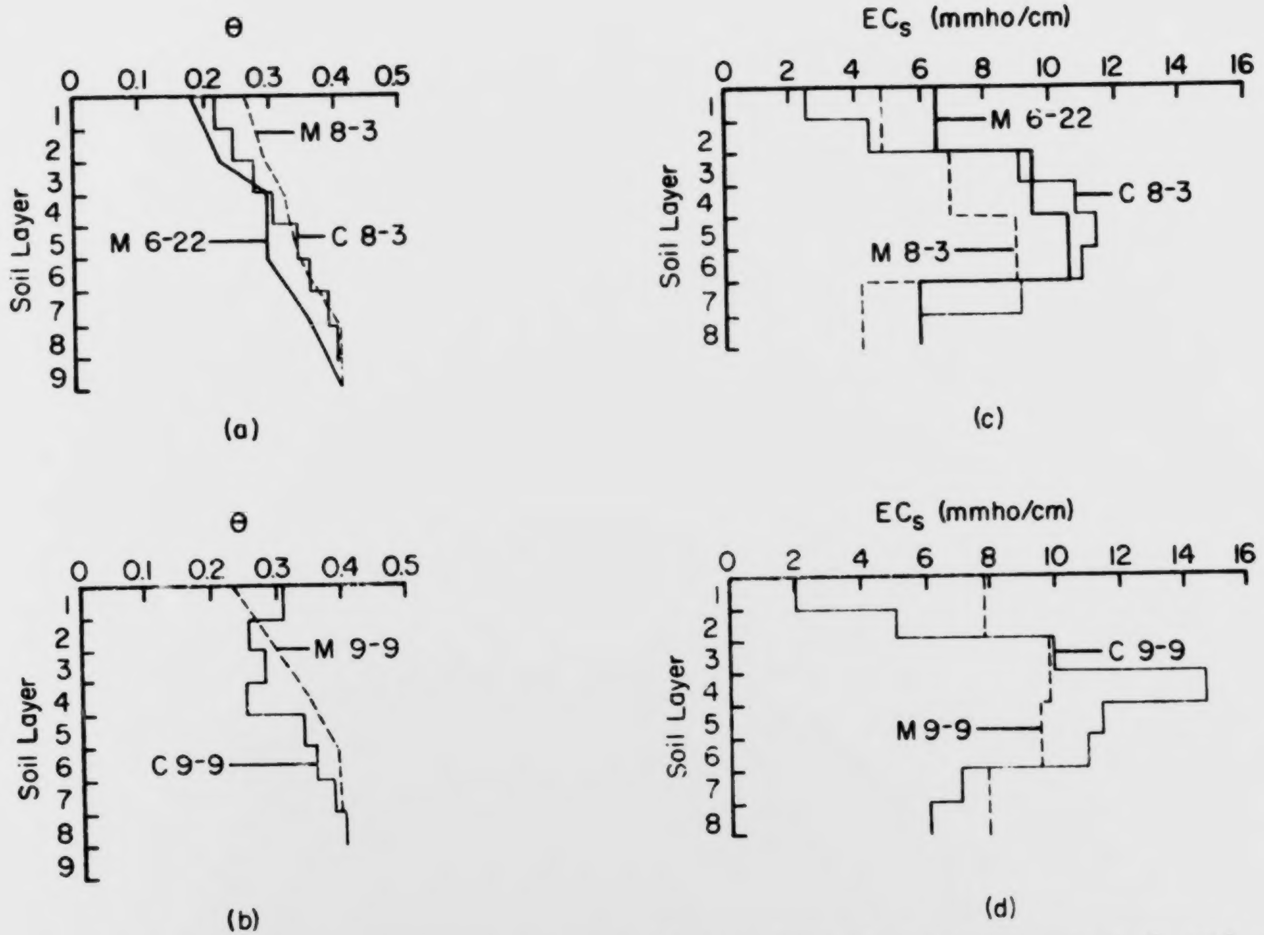

Figure 13. Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, for Block 6.

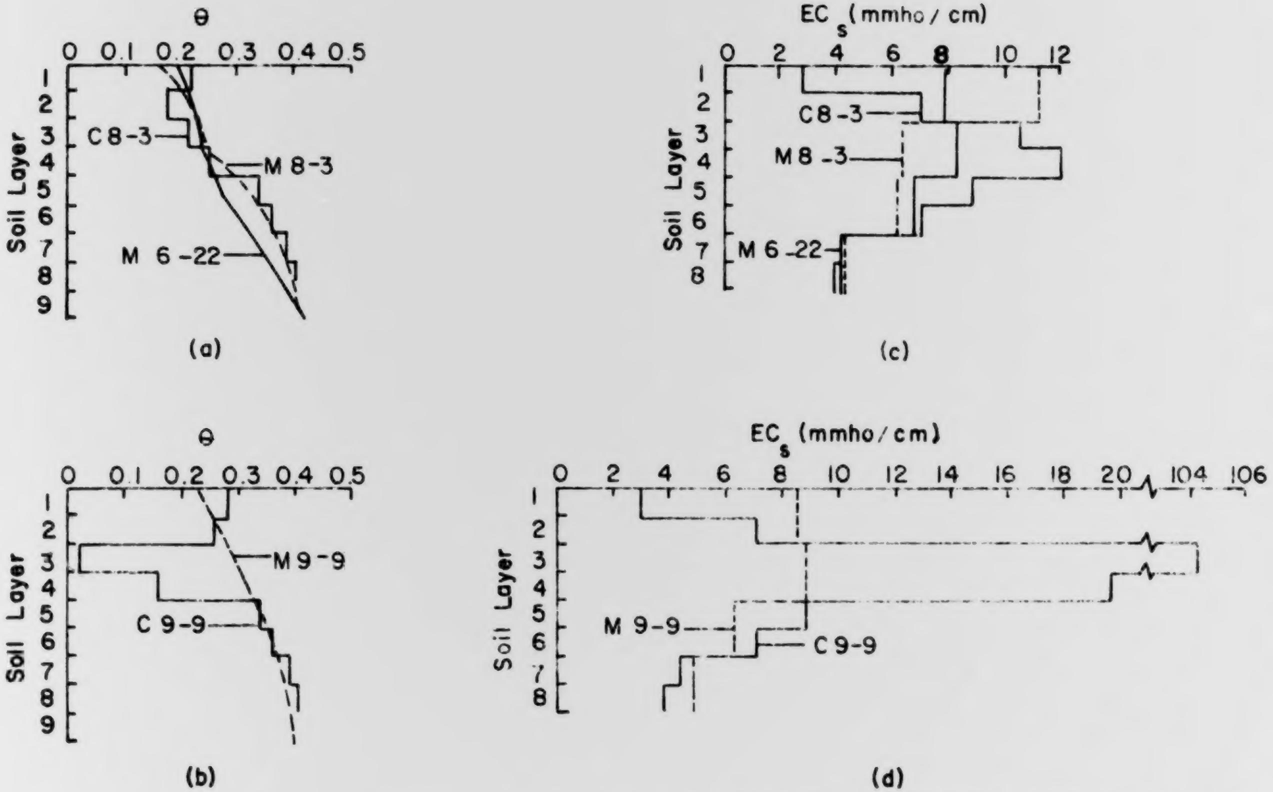

Figure 14. Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, for Block 7.

Table 22. Net upward movement of water into the soil profile, as determined from total irrigation water applied, total ET, and soil moisture measurements.

| Period | Block | (1) Total Irrigation Water Applied (inches) | (2) Irrigation Water Minus ET (inches) | (3) Measured Increase in Soil Water During Period (inches) | (4) Net Upward Movement During Period (inches) * | (5) Accumulated Net Upward Movement (inches) |
|---|---|---|---|---|---|---|
| June 22-Aug. 3<br>Total ET = 8.77in | 3 | 11.00 | 2.23 | 2.63 | 0.40 | 0.40 |
| | 5 | 9.83 | 1.06 | 2.51 | 1.45 | 1.45 |
| | 6 | 11.00 | 2.23 | 2.52 | 0.29 | 0.29 |
| | 7 | 9.95 | 1.18 | 1.12 | -0.06 | -0.06 |
| Aug. 4-Sept. 9<br>Total ET = 6.11 in | 3 | 10.98 | 4.87 | 1.50 | -3.37 | -2.97 |
| | 5 | 7.48 | 1.37 | 0.92 | -0.45 | 1.00 |
| | 6 | 6.48 | 0.37 | 0.57 | 0.20 | 0.49 |
| | 7 | 5.23 | -0.88 | -1.04 | 1.92 | 1.86 |

* Column 3 minus column 2

The calculated moisture content was usually less than measured values in the upper four soil layers. Such differences could be attributed to actual upward movement of water in the field which could not occur in the model. However, part of the difference may be due to not allowing moisture extraction by ET in the model below the fourth layer. Figures 11 a, 11 b, 12 a, and 12 b show situations in which measured and calculated $\theta$'s would agree better if the ET extraction was extended deeper into the soil profile. That is, if part of the ET came from layers 5 and 6, the calculated $\theta$ would be less in these layers and greater in layers 1 through 4. Determination of root extraction pattern in the field is an extremely difficult task. Excavation for new drain construction in the spring of 1972 revealed numerous plant roots at depths greater than 2 feet (bottom of layer 4).

The lack of capability of the model to account for redistribution of soil moisture is emphasized in Figure 14 b wherein the calculated $\theta$'s of layers 3 and 4 are considerably less than measured values. This situation resulted when light, frequent irrigations were applied (see Table 20). Insufficient water was applied for the model to calculate any percolation past the second layer into the third or fourth layers in the period from August 3 to September 9 in Block 7. Consequently, the moisture was continuously depleted from these two layers by evapotranspiration since water could not enter from top or bottom of these layers in the model. Differences in soil-water potential would obviously not allow this situation to exist under field conditions.

Figure 13 b illustrates the error that may result from selecting wrong values of $\theta_{fm}$. Layers 5 - 8 are filled to $\theta_{fm}$, yet the measured moisture content in these layers is greater than calculated. This result cannot be explained since soil moisture measurements that were used to determine $\theta_{fm}$ were made after an irrigation of sufficient depth to fill the soil to the upper limit of field moisture in all layers. Since the water table was lower on September 9 than on the day when the $\theta_{fm}$ values were determined, the situation could not be reconciled. The situation shows the importance of selecting the proper values of $\theta_{fm}$.

A fluctuating water table would be difficult to simulate with the simplified model. The difficulty arises primarily from the influence of water table fluctuations on $\theta_{fm}$. A fluctuating water table might be modeled in two different ways. First, the total season could be separated into periods in which the water table and $\theta_{fm}$ values could be considered constant. The computer program could be operated in a stepwise fashion by inputing the proper values of $\theta_{fm}$ for each period. The second way of operating the model would be to use the average water table depths and constant values of $\theta_{fm}$ for the entire season. The second approach was used for the results of this report.

Salt Movement. Since water serves as the transporting medium for the dissolved salts, any errors in predicting water movement compound the problems of accurate prediction of salt movement. Figures 11 through 14 show that agreement between calculated and measured $EC_s$ is generally poor. To minimize the errors in the calculated $EC_s$ profiles that result from the differences in calculated and measured $\theta$, the moisture extraction pattern was changed for Blocks 3 and 5 such that the average difference between measured and calculated $\theta$ at the two checkpoints was equal for all layers. Table 23 shows the resulting extraction patterns. Extraction by ET was limited to the top five layers of Block 5. Figures 15 and 16 show the resulting $\theta$ and $EC_s$ profiles. This exercise showed that the model is not extremely sensitive to errors in the moisture extraction pattern; i.e., large changes in percent extraction of a layer are needed to produce significant changes in moisture content.

Table 23. Percent moisture extracted by plant roots that is required to match calculated moisture content profiles to corresponding measured profiles.

| Soil Layer | Percent Moisture Extraction Block 3 | Percent Moisture Extraction Block 5 |
|---|---|---|
| 1 | 16 | 40 |
| 2 | 16 | 17 |
| 3 | 13 | 10 |
| 4 | 11 | 11 |
| 5 | 11 | 12 |
| 6 | 11 | |
| 7 | 8 | |
| 8 | 8 | |
| 9 | 6 | |

From Figures 15 and 16, it appears that the model predicted more leaching than actually occurred. Salts from the upper layers were moved downward by the model to a greater extent than actually occurred according to measurements. The measured values in Figure 15 indicate that the change in $EC_s$ between June 22 and August 3 and between August 3 and September 9 was due primarily to the increase in moisture content. The shape of these measured profiles remained essentially the same. The change in the profile for Block 5 (Figure 16) cannot be so explained. In this case the profile remained nearly the same shape (except for layers 5 and 6) but concentrations generally increased as the moisture content increased between June 22 and August 3.

An effort was made to reduce the predicted salt leaching by making a change in the leaching factor subprogram. The effluent ratio (ER) was multiplied by 0.5 before computing the leaching factor. Figures 17 and 18 show that leaching was reduced but that although calculated $EC_s$ profiles were different, agreement between measured and calculated profiles was not significantly improved. Calculations were also made wherein the effluent ratio was multiplied by 0.7 and 0.3 with no better results. The sensitivity of the model to changes affecting the leaching factor function is exhibited by this work.

Earlier discussion on data used in the model is significant in the analysis of the effectiveness of the model to describe salt movement. In addition to the problems dealing with determining $EC_e$, error also resulted from changing values of $EC_e$ to $EC_s$. Perhaps more important is the fact that with the exception of Block 5, only one moisture content profile was determined on each of the three sampling dates, and this was at a different location than where soil samples were taken for $EC_e$ determination. The correlation between moisture content and concentration of the soil solution as input to the model and at two checkpoints may therefore be questioned.

## Detailed Model

### Water Model

The computer program for the water model (Appendix B) developed from Equation 45 was used to predict evapotranspiration, soil water flow, and soil water content profiles as functions of time on the Hullinger

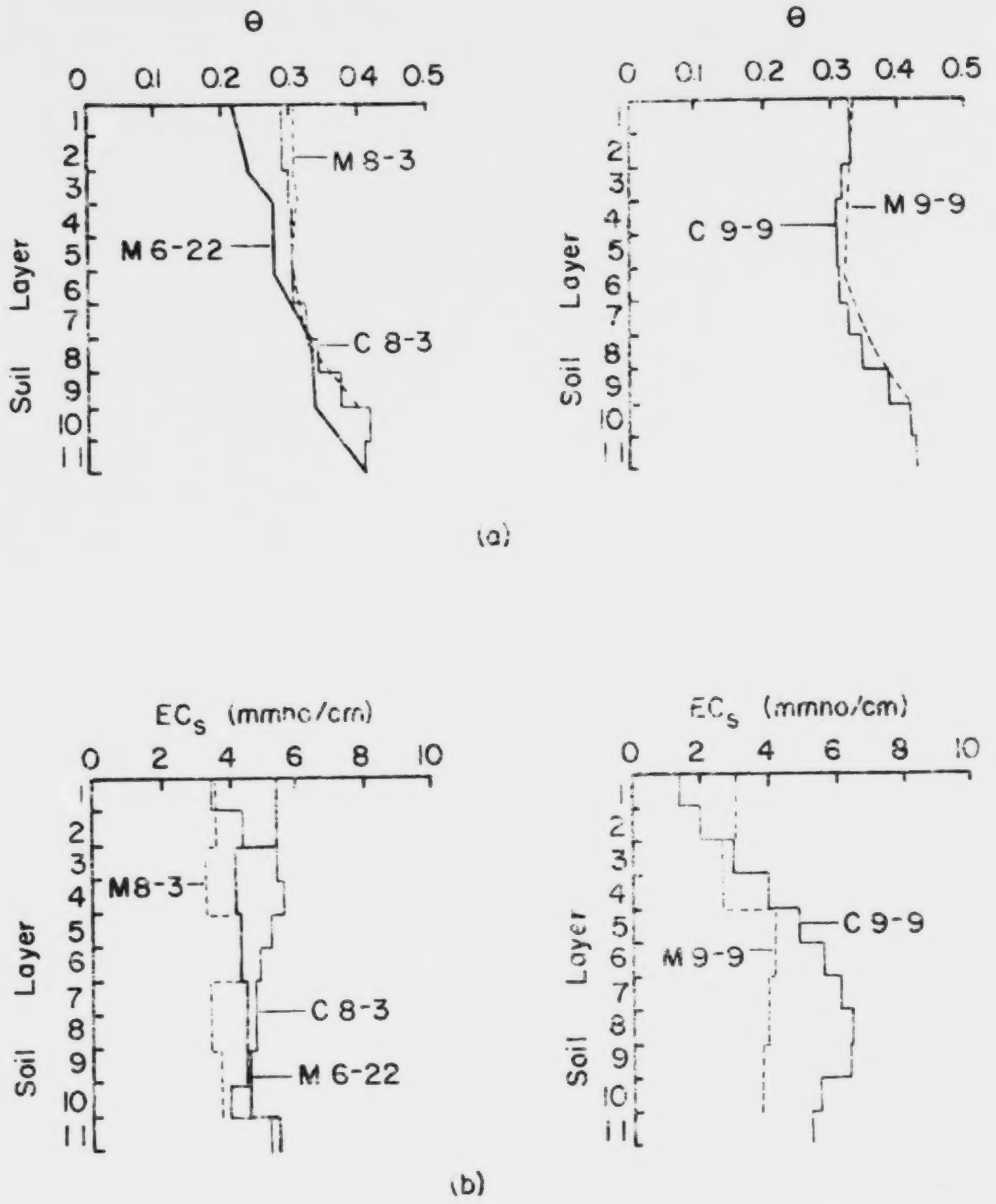

Figure 15. Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, after adjusting moisture extraction pattern to minimize differences in calculated and measured θ profiles for Block 3.

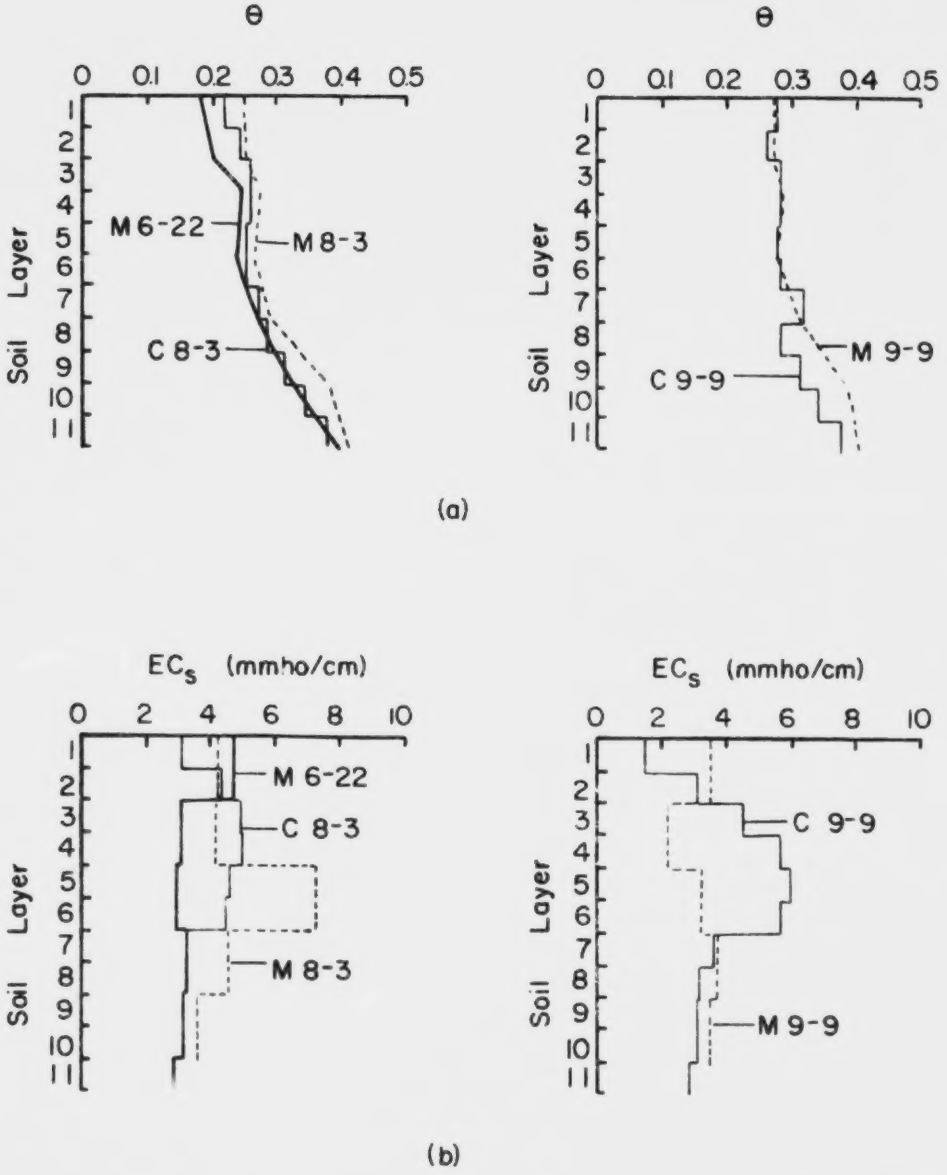

Figure 16. Comparison of measured (M) and calculated (C) profiles of moisture content, θ, and electrical conductivity of soil solution, $EC_s$, after adjusting moisture extraction pattern to minimize differences in calculated and measured θ profiles for Block 5.

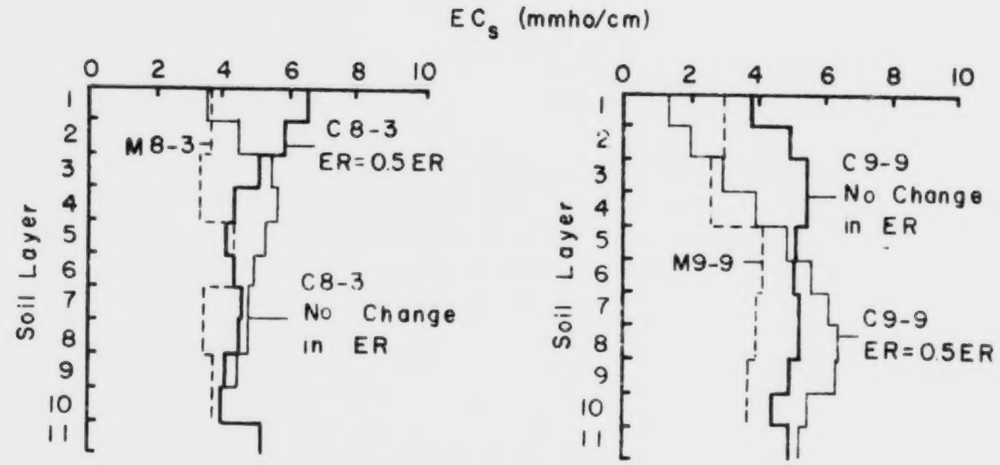

Figure 17. Measured (M) $EC_s$ for Block 3 compared with calculated (C) values resulting from letting ER = 0.5 ER, ER is effluent ratio.

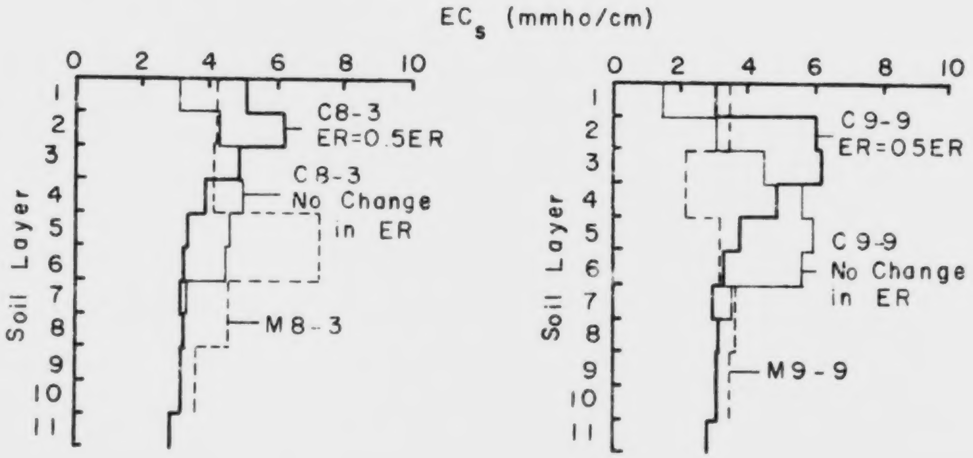

Figure 18. Measured (M) $EC_s$ for Block 5 compared with calculated (C) values resulting from letting ER = 0.5 ER, ER is effluent ratio.

farm. The crops used were oats in 1970, and alfalfa in 1971. Predicted values were compared to the actual as measured in the field.

The program predictions covered nine days of the 1970 growing season, and the entire growing season in 1971 for a fixed irrigation interval of 10.5 days. The results show the soil water profiles, evapotranspiration, drainage, and plant root potential as a function of time.

Input Data Used in 1970 and 1971. The input data used for the computation are tabulated in Appendix C, Tables 51, 52, 53, and 54. Figures 4 and 5 show the soil properties as determined by Andrade (1971) for undisturbed samples (data were extrapolated to cover the whole range of the soil water content). Tables 52 and 53 (Appendix C) also show the plant root distribution for the two crops.

Figure 19 and Table 54 (Appendix C) show the potential flux at the surface for 1970 and 1971, respectively. The fluxes include the rate of potential evapotranspiration and precipitation (rain and/or irrigation) as functions of time forthe total time of computation. These data are the surface boundary conditions needed for the computation. The bottom boundary condition was a constant pressure head at 165 cm (the water table).

Results. The program was run for one irrigation interval during 1970 due to the lack of continuous field data for comparison of actual versus computed data. The computed results of 1970 and 1971 as compared to the actual measurements are shown in the following order:

1. Soil water profiles at different times of season.
2. Evapotranspiration as a function of time.
3. Water flow through the lower boundary as a function of time.
4. Plant root potential as a function of time.

Soil Water Profiles. Figure 20 shows the actual and computed water content profiles for oats in 1970. Water contents were measured by the neutron probe at 30, 45, 75, 105, 135 and 165 cm depth. A linear relation was assumed to exist between any two depths. For the top 30 cm, the water content at 75 and 30 cm was extrapolated linearly. This was done because the effective diameter of the neutron probe was

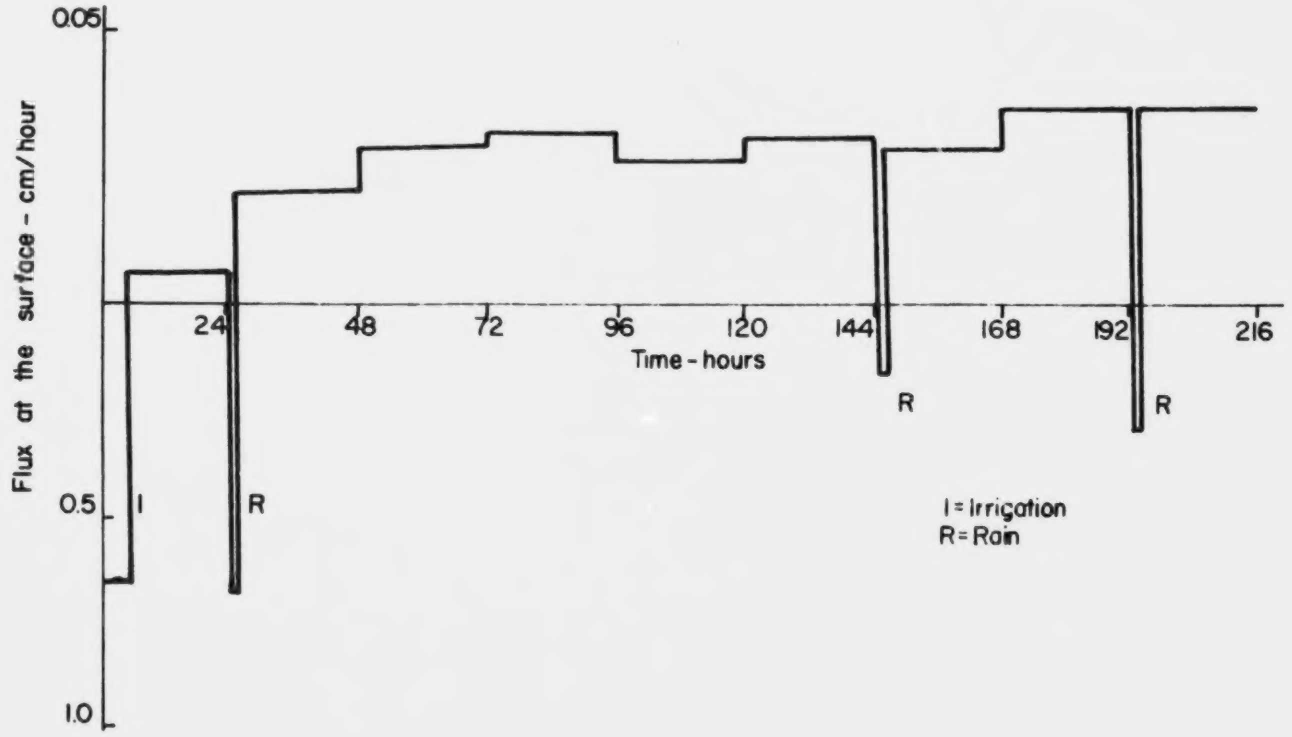

Figure 19. Water flux at the surface (evapotranspiration and precipitation, cm/hr) vs time for oats in the 9-day interval in 1970.

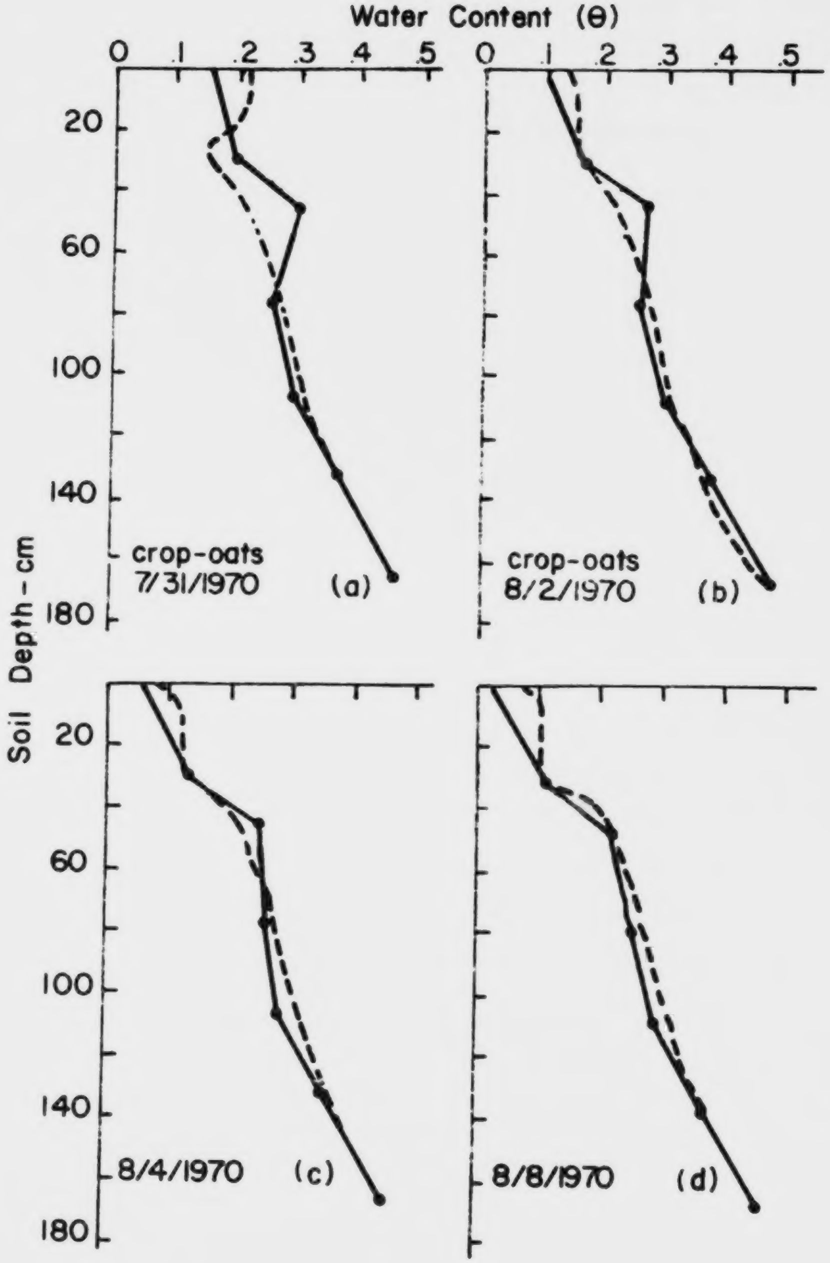

Figure 20. Comparison of the water content profiles as predicted (dotted) and measured (solid) for oats in 1970. (a) 24 hrs, (b) 72 hrs, (c) 120 hrs, (d) 216 hrs

more than 30 cm, so no points could be measured between 0 and 30 cm. The comparison was better when the redistribution stage reached an end.

For alfalfa in 1971, similar results were reached as shown in Figure 21 for the first crop, Figure 22 for the second crop, and Figure 23 for the third crop. The results of computed and actual soil water content showed excellent agreement, especially after 48 hours of irrigation or heavy rain.

Figure 24 shows water content with respect to time for alfalfa in 1971 for the entire season of 116 days. The computed values agree very well at all depths with the measured. The greatest difference was at 30 cm depth. The disagreements at 30 cm occurred mostly after irrigation in the redistribution stage. This might be due to the assumption that there was no hysteresis effect on the soil properties, and/or due to the nonuniform field soil.

Evapotranspiration. Figure 25 shows a comparison among the computed, actual and Penman cumulative evapotranspiration (ET) for 1970. The actual ET was measured from daily readings of two lysimeters installed in the field, the Penman ET was calculated from Equation [97] using measured field data. The model computed 4.9 cm cumulative ET in 1970 which was 0.4 cm less than the actual ET. This might be due to two factors:

1. The root distribution was assumed uniformly distributed to a depth of 30 cm, which is generally not true.
2. The value of Hroot reached the minimum allowable (-15 bars) at 155 hours where the cumulative computed ET started to become less than the cumulative actual ET, as shown in Figure 25. The minimum value allowed for Hroot, -15 bars, was chosen arbitrarily. Lower values of Hroot -20 or -40 bars would have decreased the difference between cumulative computed ET and cumulative actual ET. This condition was considered and details of its effect are discussed in a later section.

The ratio of actual to potential evaporation (E) seemed to vary with the irrigation cycle and the stage of growth of the crop (Figure 26). At 938 and 1945 hours, the decrease in the ratio of actual evapotranspiration (ET) to potential (E) was caused by cutting the alfalfa crop. The ratio

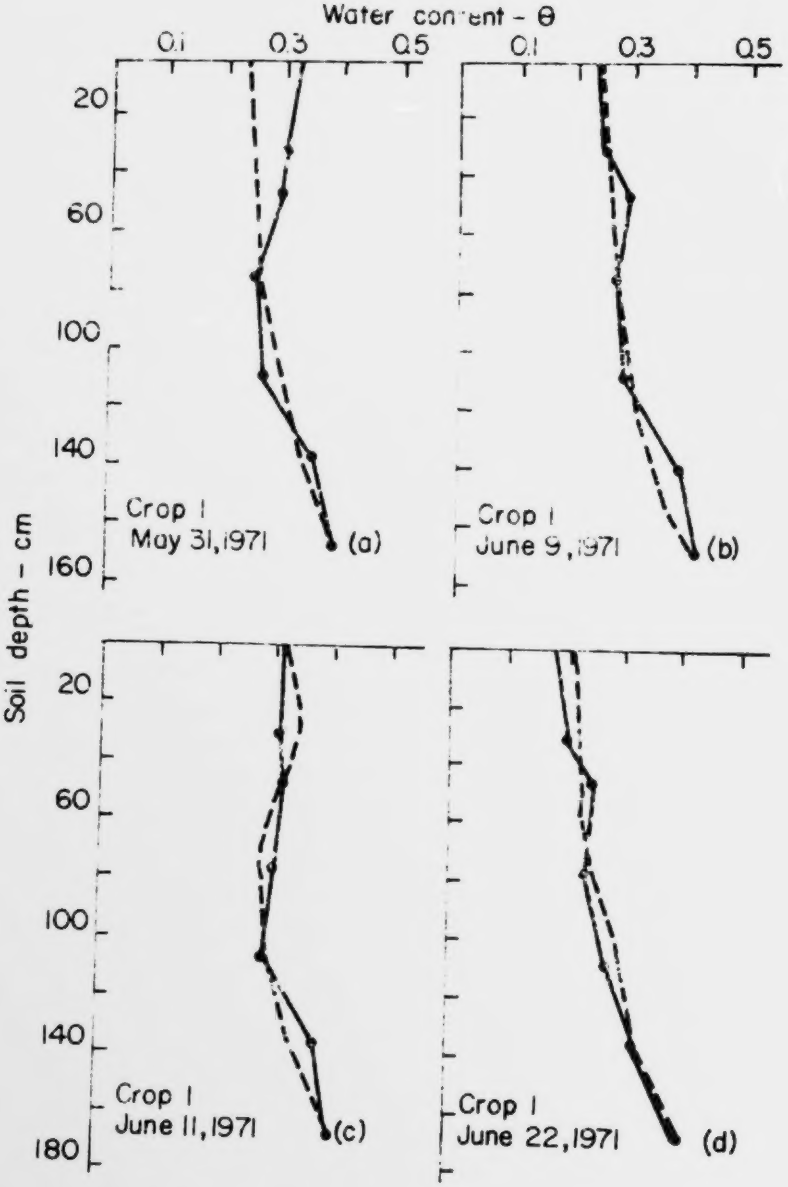

Figure 21. Comparison of water content profiles as measured (solid) and predicted (dotted) for crop 1 alfalfa in 1971. (a, c) 24 hrs after precipitation, (b, d) end of irrigation interval.

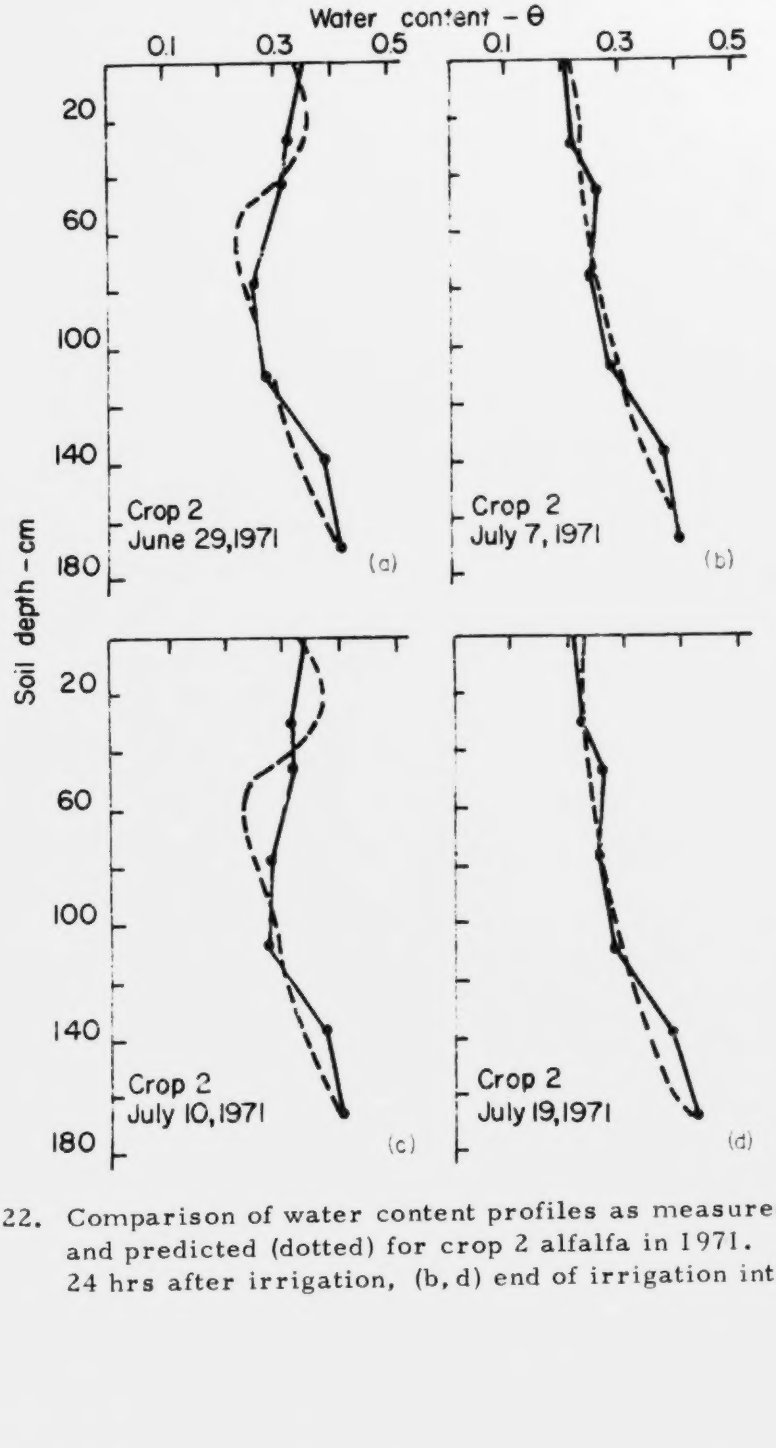

Figure 22. Comparison of water content profiles as measured (solid) and predicted (dotted) for crop 2 alfalfa in 1971. (a, c) 24 hrs after irrigation, (b, d) end of irrigation interval.

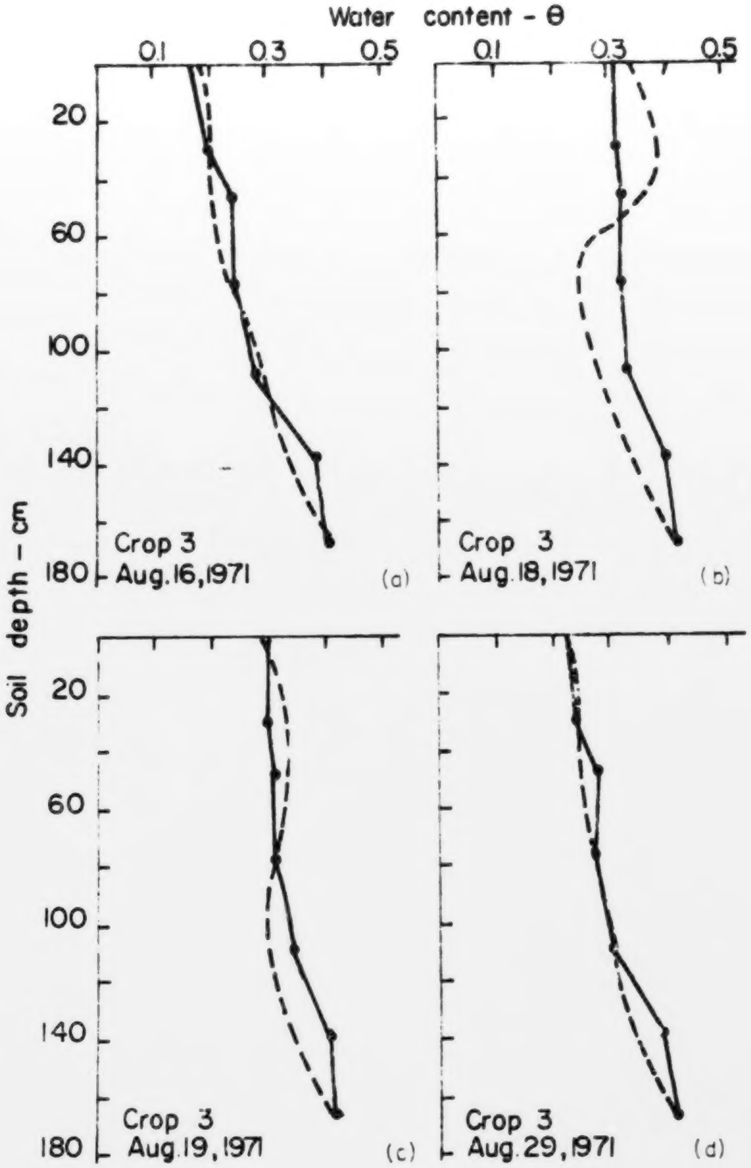

Figure 23. Comparison of water content profiles as measured (solid) and predicted (dotted) for crop 3 alfalfa in 1971. (a) end of irrigation interval, (b) 24 hrs after irrigation, (c) 48 hrs after irrigation, (d) end of irrigation interval.

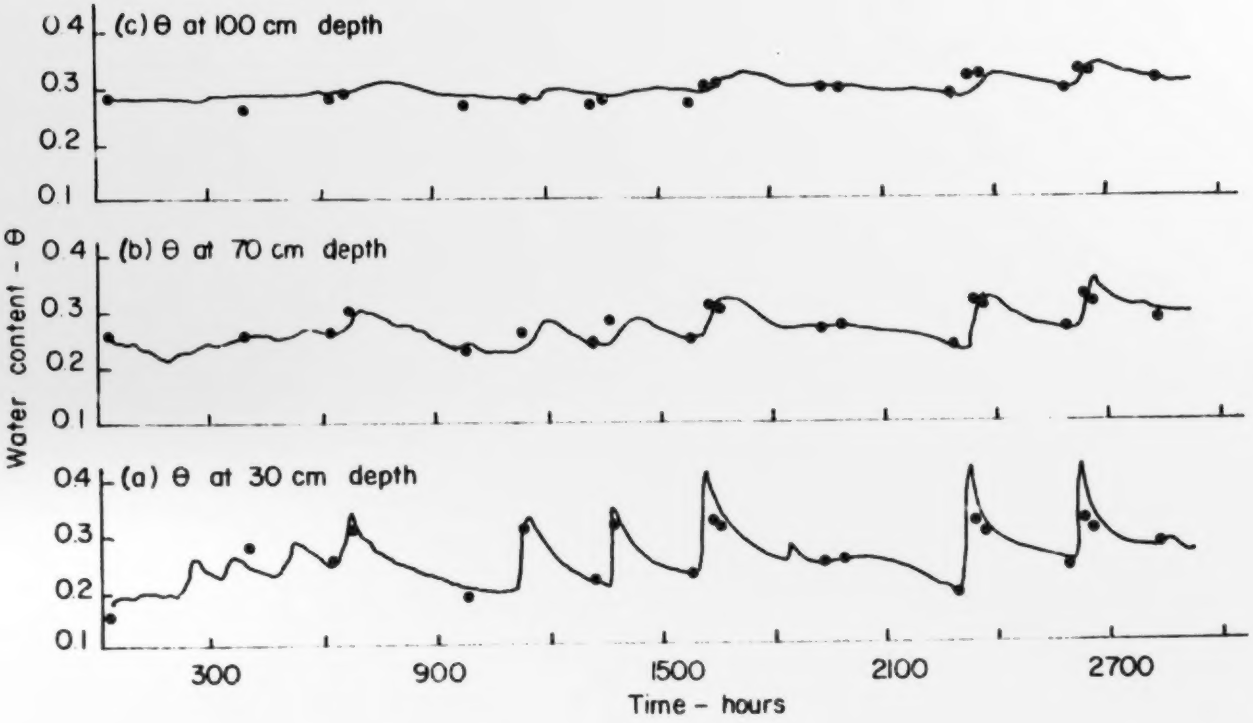

Figure 24. Comparison of measured (dots) and predicted (solid lines) water content profiles for alfalfa in 1971. (a) 30 cm, (b) 70 cm, (c) 100 cm depth.

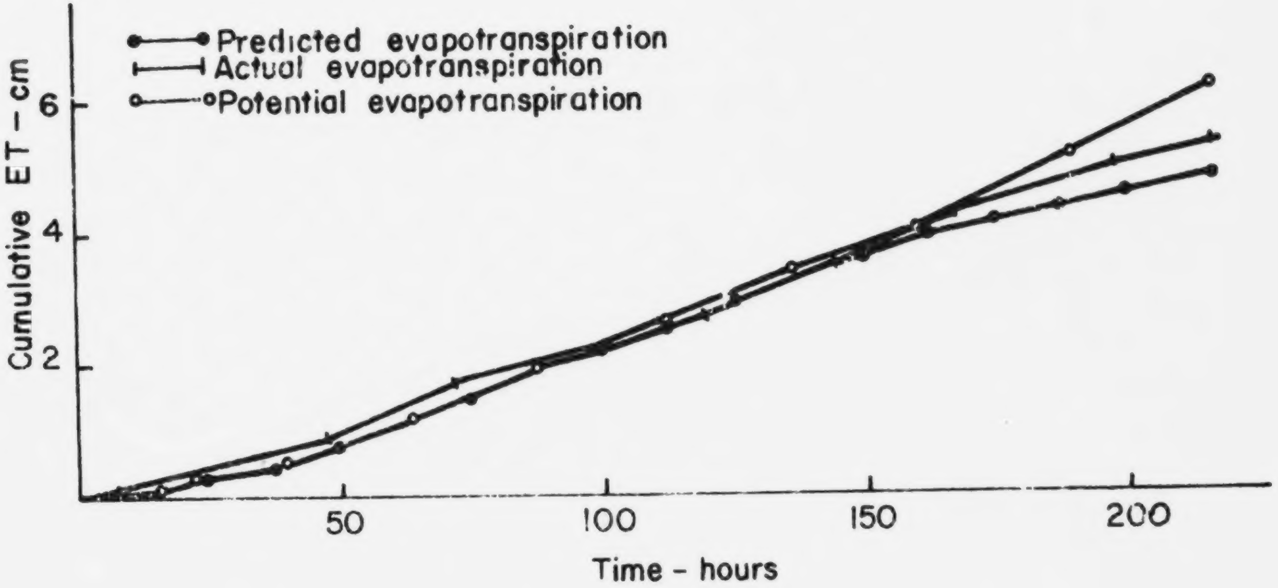

Figure 25. Comparison of actual, predicted, and potential evapotranspiration during the 9-day period with that predicted for oats in 1970.

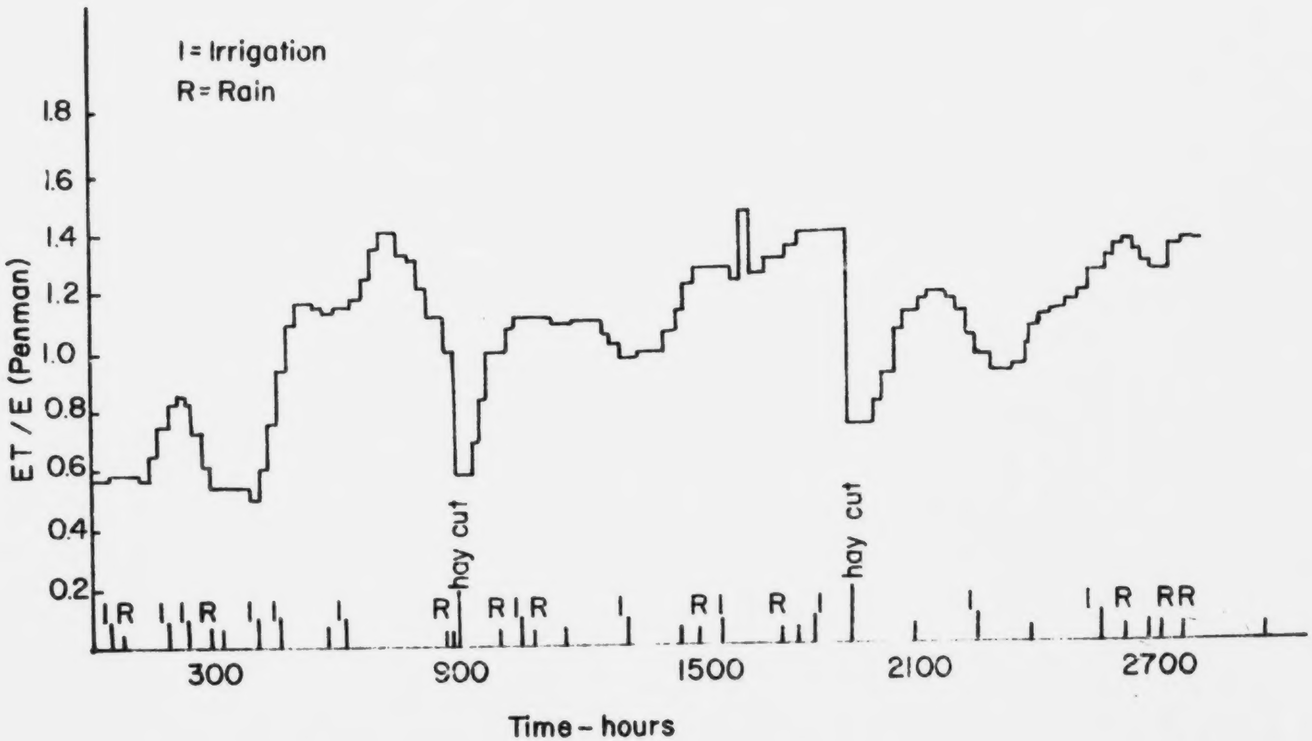

Figure 26. Variation of actual ET/Penman E for alfalfa in 1971.

of actual ET to potential E varied from about 0.57 to 1.48 and averaged about 1.06. The lowest ratios occurred, as expected, after cutting or early in the season. It was originally intended to use values of the crop factor (i.e., the ratio of actual ET to potential E) published for other regions for estimating ET. This resulted in considerable error in the computed versus measured values over short periods, although the long period errors were smaller. Consequently, it was assumed that the actual ET was equal to the potential ET for the computations to follow for evaluation of the other predictions other than ET. The irrigation amount was sufficiently high so that the value of Hroot was always above the limiting value (Figure 27). Thus, the computed ET should be equal to the measured ET. This indicates that for detailed estimation of ET, the use of a generalized crop factor with a Penman type E measurement may be considerably in error even if soil water is not limiting. Possibly, this is due to underestimation of the influence of advection by the Penman equation (when the ratio is more than 1). When the ratio is less than 1.0 as after cutting there is undoubtedly a plant factor responsible, and a possible change in the relation of potential evaporation to transpiration not accounted for in the model.

Flow from/to the Water Table. In the 1970 growing season, only upward flow from the water table occurred in the nine days test interval. Figure 28 shows that the computed cumulative upward flow added up to 2.2 cm which was 0.1 cm greater than the actual. The actual upward flow was measured by measuring the right hand side components of Equation [117].

$$\text{FLOW} = \Delta M_0 - I + ET \qquad [117]$$

where $\Delta M_0$ is the change in moisture content in the field, as measured by the neutron probe, I is irrigation or precipitation, ET is evapotranspiration as measured by the lysimeters, and FLOW is flow through the lower boundary. If FLOW is positive, the flow through the lower boundary is upward, otherwise it is downward.

Figure 29 shows the cumulative flow through the bottom boundary as compared to the actual for 1971. The actual upward flow was consistently greater than the predicted except at the end of the first crop. The total actual upward flow was 4.8 cm as compared to 0.0 cm predicted for the entire growing season (116 days). This difference might

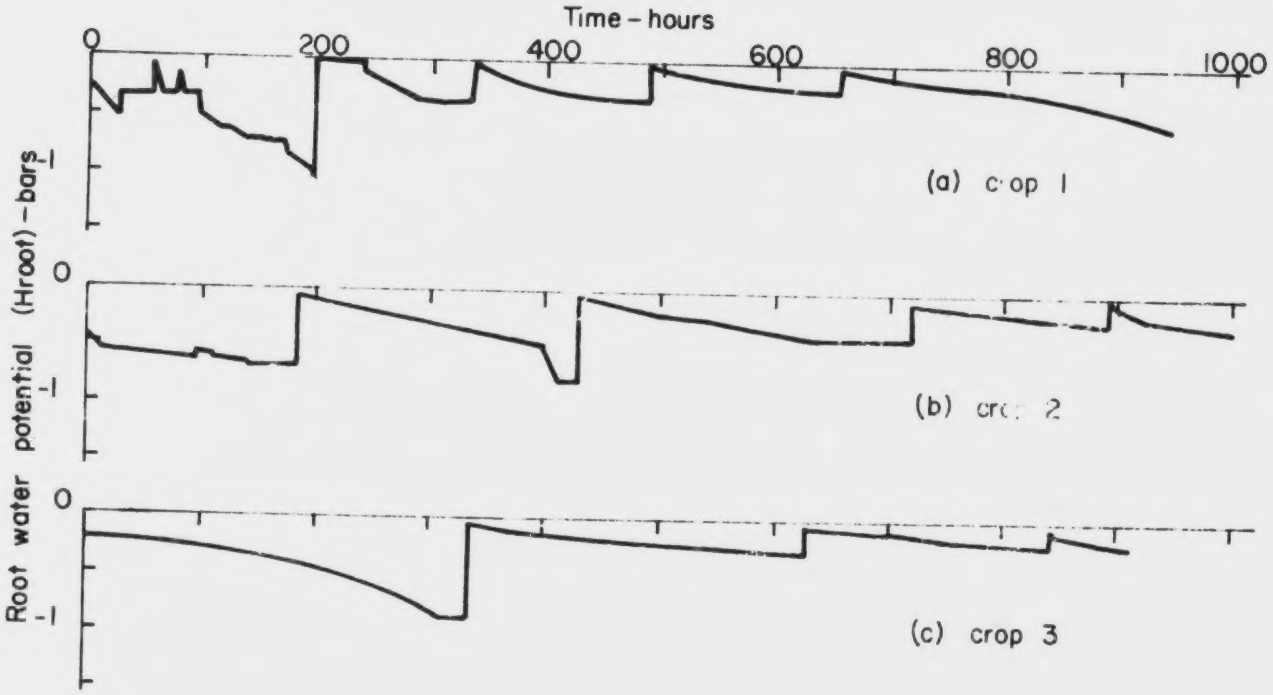

Figure 27. Variation of root water potential of alfalfa in 1971. The increase in Hroot is due to precipitation. (a) crop 1, (b) crop 2, (c) crop 3.

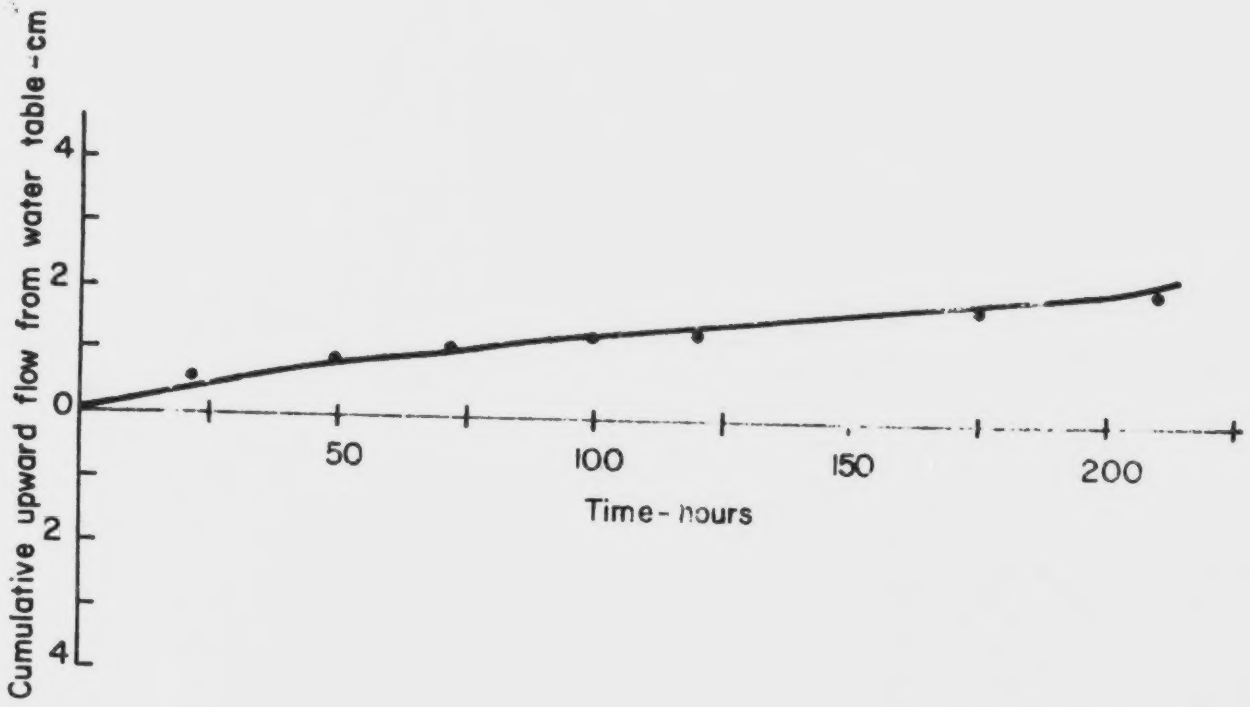

Figure 28. Comparison of actual (dots) and predicted (solid line) upward flow from the water table for oats during the 9-day interval in 1970.

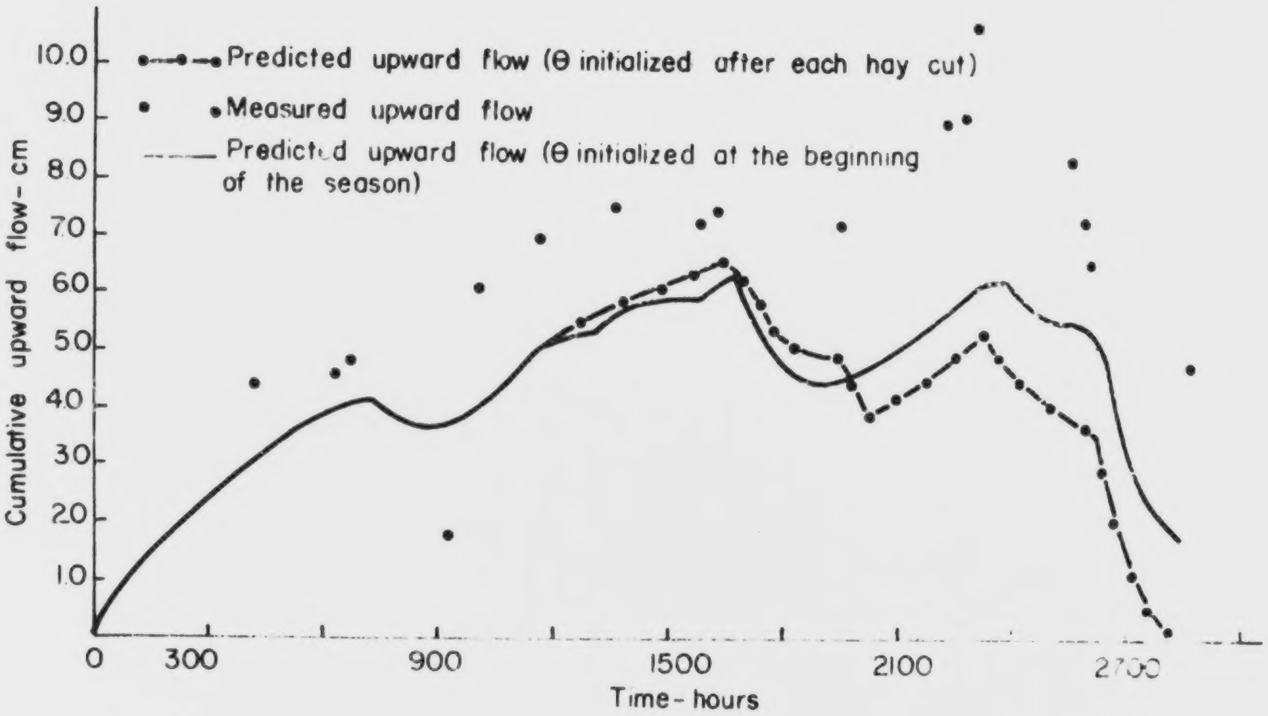

Figure 29. Comparison of actual (dots) and predicted (solid line) upward flow of water from the water table for alfalfa in 1971.

be due to the uncertainty of measurement of water content in the top 30 cm of depth was the average for that depth. Figure 29 shows that late in the season, or at 2400 hours, 19 days before the cut of the third crop, downward flow to the water table started. This was due to the larger amount of water applied to induce downward flow. The trends of predicted and actual data agree during this period.

Root Water Potential (Hroot) at the Surface. Figure 30 shows the variation of Hroot during the nine-day interval for oats. The Hroot reached -15 bars, which is the minimum allowable beyond which wilting occurs at 155 hours. Figures 27 and 30 show that Hroot increased when precipitation occurred, and decreased when the water content decreased toward the end of the irrigation cycle. In 1971, as shown in Figure 27, Hroot rarely reached -1 bar; this might be due in part to the greater depth of the root system for alfalfa as compared to oats in 1970, but it was primarily due to increased addition of water. In both years, the average conditions over the day were used as a boundary condition. Consequently, predicted changes of Hroot values with time during the day did not occur. It would be more realistic, but cost more field and computer time, if the potential ET was varied with time during the day for both seasons. If this was allowed, the program would be expected to predict the variations in Hroot values during the day, since it predicted the variations during the whole season.

Sensitivity of Water Model. The sensitivity of the model to various parameters was tested by comparison of two soil conditions (A + B). Most of the tests were conducted for the data from the nine-day interval in 1970. The pressure potential was varied in these two conditions as shown in Figure 4. Condition A caused evapotranspiration and transpiration to be greater than condition B, while the reverse was true for evaporation and upward water flow. The comparison is tabulated in Table 24.

The water content profiles were quite different in the active root extraction zone. At the end of the period the water content at 30 cm depth was about 0.10 for condition A and about 0.12 for condition B, Figure 31 shows these data. For these computations Hroot fell to -15 bars one day earlier for condition B than for condition A (Figure 28).

Another test of sensitivity of the model was made using different root extraction depths of 30, 45, and 60 cm for oats in 1970. Evapotranspiration and upward flow from the water table for the 45 and 60 cm root

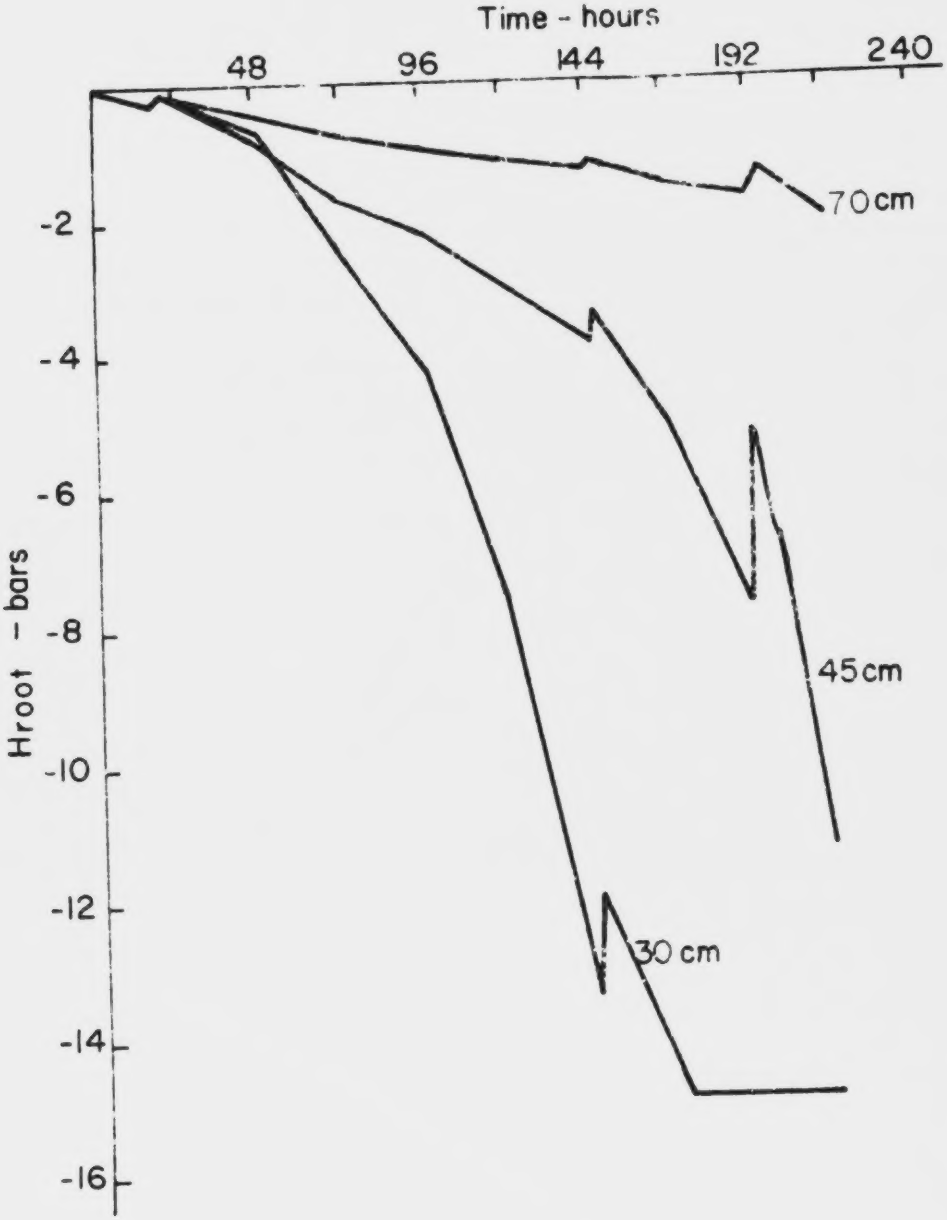

Figure 30. Hroot during the 9-day period as predicted from 30, 45, and 70 cm root distribution.

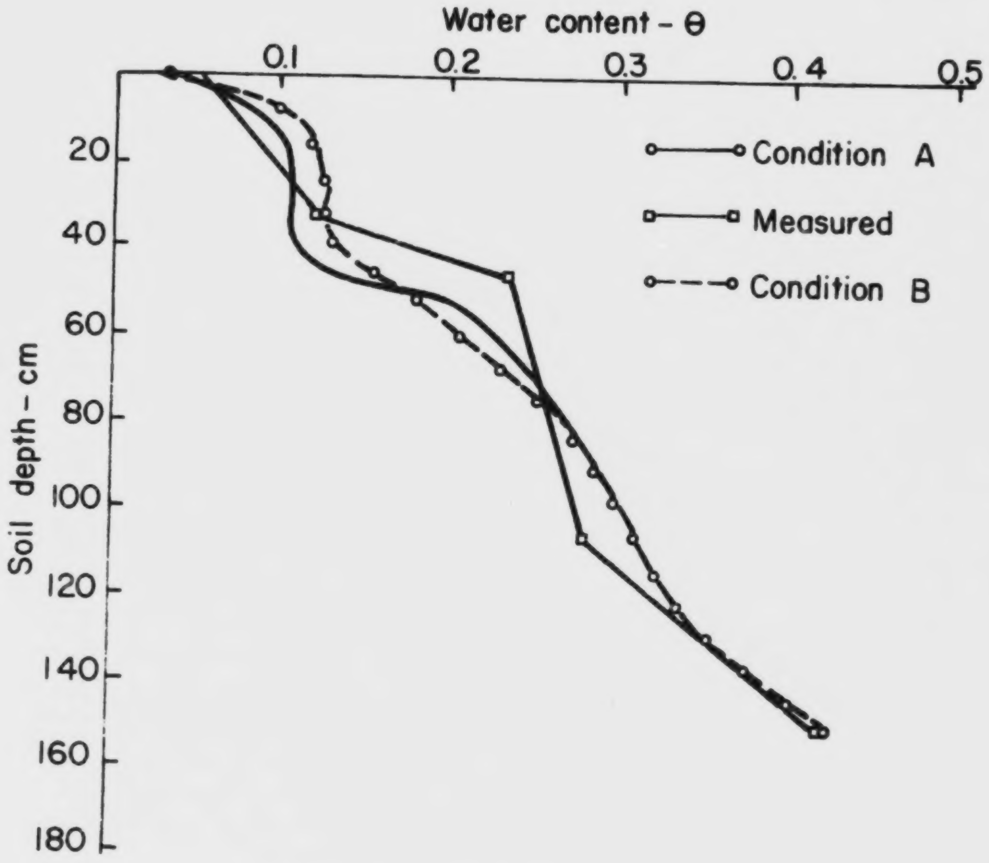

Figure 31. Comparison of measured water content profiles for soil condition A and B at the end of the 9-day period in 1970, oats.

extraction were higher than the actual and the 30 cm root extraction. The results are tabulated in Table 25.

Table 24. Comparison of predicted evapotranspiration, evaporation, transpiration, and water flow as influenced by different soil properties for a nine-day period starting July 28, 1970 at Vernal, Utah (no precipitation).

| | Condition A<br>45 cm root depth | Condition B<br>45 cm root depth |
|---|---|---|
| Evapotranspiration | 6.01 cm | 5.79 cm |
| Evaporation | 0.64 cm | 0.77 cm |
| Transpiration | 5.37 cm | 5.02 cm |
| Water flow from the water table | 2.44 cm | 2.58 cm |

Table 25. Comparison of evapotranspiration, upward flow of water from the water table and Hroot at the end of the nine-day interval in 1970.

| Root depth | Evapotranspiration (cm) | Upward water flow (cm) | Hroot-bars (end of interval) |
|---|---|---|---|
| 30 cm | 4.9 | 3.2 | -15 |
| 45 cm | 5.8 | 2.3 | -11 |
| 60 cm | 5.8 | 2.7 | - 2 |
| Actual | 5.3 | 2.1 | |

The predicted water content profiles varied from the measured with the 30 cm root extraction giving best results compared to the measured as shown in Figure 32. In this test, the flux at the surface was varied. Potential evaporation was assumed to be 10 percent and 50 percent of potential evapotranspiration. The program was run for these two

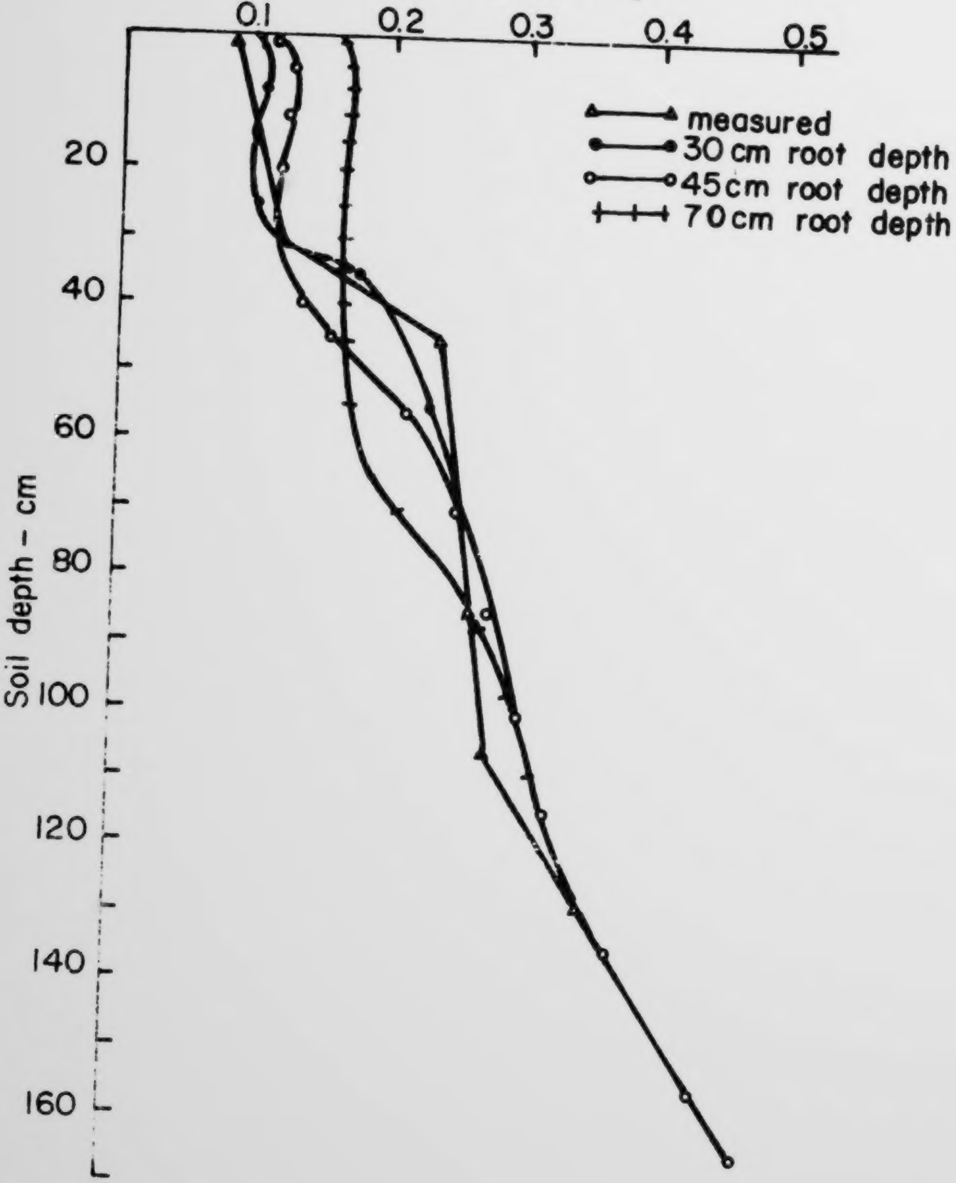

Figure 32. Comparison of measured and predicted water content profiles at the end of a 9-day period in 1970 assuming root distribution 30, 45, and 70 cm.

conditions and for the three root depths. The results are tabulated in Table 26. These computations show that ET and upward flow from the water table are less when E is greatest. The $\theta$ profiles show E = 0.1 ET to be the most reasonable.

Table 26. Effect of change in upper boundary condition and root depth on evaporation, transpiration and upward water flow (11 days).

| Surface flux | E = 0.1 ET | | | E = 0.5 ET | | |
|---|---|---|---|---|---|---|
| Root depth - cm | 30 | 45 | 60 | 30 | 45 | 60 |
| Evaporation | .62 | .62 | .62 | 2.68 | 2.99 | 2.99 |
| Transpiration | 5.70 | 6.37 | 6.37 | 3.26 | 3.58 | 3.58 |
| ET | 6.32 | 6.99 | 6.99 | 5.94 | 6.57 | 6.57 |
| Upward water flow | 5.43 | 6.35 | 7.76 | 5.38 | 5.94 | 6.78 |

A sensitivity test was run on the data of the 1971 growing season. In this test, the initial moisture content was reinitialized at the beginning of each crop as compared to one initial moisture content at the beginning of the season. The water content profiles were essentially the same, especially for the first irrigation after cutting in both cases, as shown in Figure 33. Figure 29 shows the difference in upward flow for both cases.

Another test of sensitivity of the model was made using data from a desert soil, where the lower limit for Hroot was varied. The original soil water content was high simulating spring conditions. Figure 34 shows cumulative ET where the lower limit was allowed to drop to -20 and -40 bars as well as cumulative potential ET. The data show that cumulative ET at 48 days was 7.6 cm for the -20 bar limit compared to 8.3 for the -40 bar limit. The computed data indicated that the lower limit of Hroot was reached at 24 days for -20 bars and 30 days for -40 bars.

From the last two tests it appears that under irrigated conditions one initial water content profile is needed at the beginning of the growing season. And, it also appears that the value chosen for the lower limit

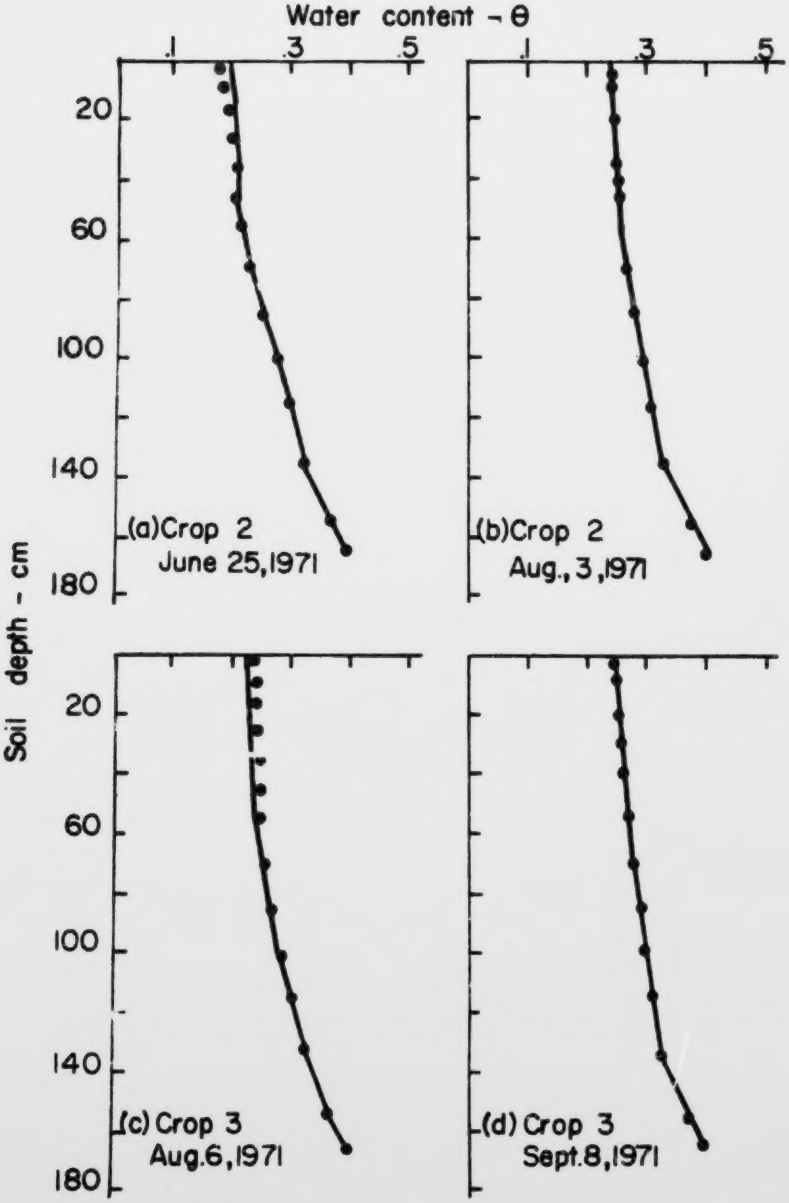

Figure 33. Comparison of water content profiles as predicted, θ was initialized after each hay cut (dots), θ was initialized at the beginning of the season (solid lines); (a, c) three days after hay cut, (b, d) at the end of the crop.

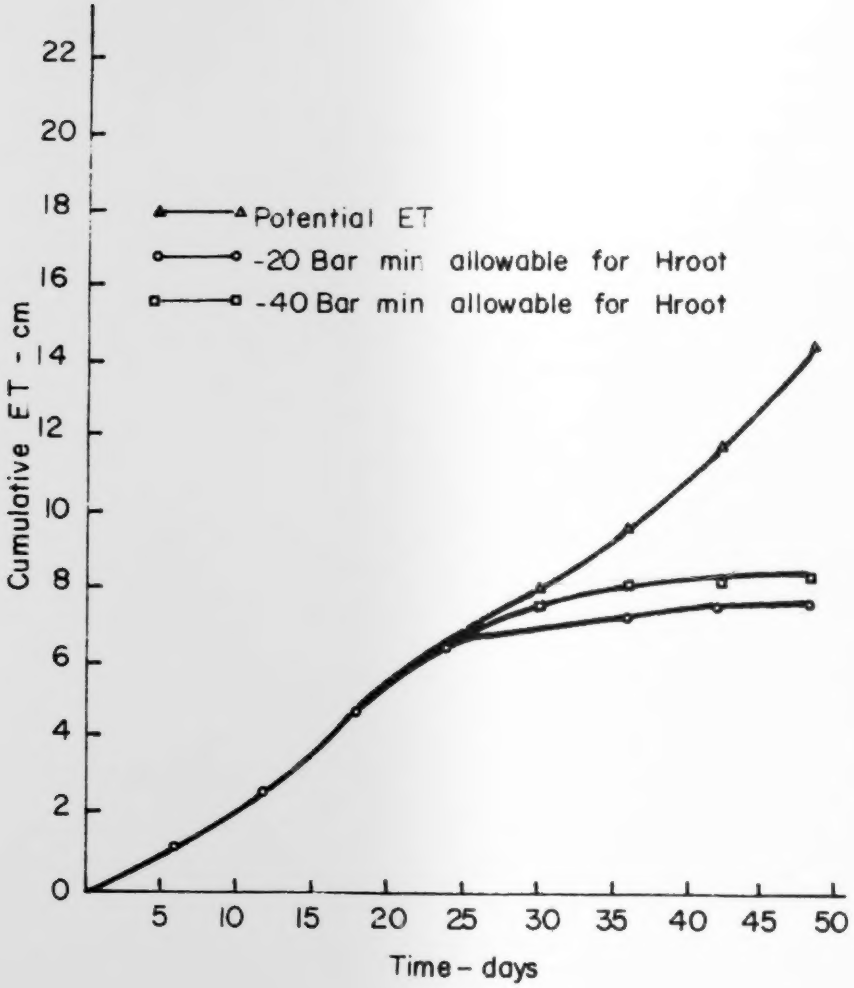

Figure 34. Cumulative evapotranspiration vs time compared with predicted evapotranspiration where the lower limit of Hroot was -40 bars and -20 bars (data for desert soil from Curlew Valley, Utah).

does not make very large differences in ET. Other than these, exact field conditions and soil properties are needed for the program to compute comparable results.

Another type of information computed is shown in Figure 35 as the relative root extraction of alfalfa as function of depth and time after irrigation. After irrigation, maximum root extraction was near the surface probably due to high water content there. As time increased the relative root extraction zone deepened. At about 150 hours, for all cases shown, the maximum extraction was near the bottom of the root zone. This was due to a higher water content there maintained by upward flow from the water table.

## Salt Model-Column Experiment

Case #1. Figure 36a is the plot of experimental and predicted soil moisture distribution after 35.6 hours of infiltration. Total salt distribution curves corresponding to the soil moisture distribution are given in Figure 36b. The predicted water content is slightly higher than the measured values at depths greater than 40 cm and vice versa at depths below 40 cm. These differences are probably due to the hydraulic parameters used in this model which were determined for an undisturbed soil while in the column the soil was loosely packed.

Observed and predicted total salt concentration (Figure 36b) have similar distribution patterns. The depth at which the maximum concentration occurs is almost the same in both cases. The concentration of salt in the upper 18 cm had the same total concentration as that of the irrigation water. However, below 18 cm there were some differences between the measured and predicted values. The predicted concentrations were less than the measured values between 18 and 33 cm while below 33 cm, the reverse was true. These differences are hard to explain with the present state of information. One of the reasons for high predicted salt concentrations below 40 cm is the low predicted water content. However, the agreement is considered good enough for most purposes.

The comparison of the experimental and predicted concentrations of individual ions comprising the total salts is plotted in Figure 37. Since the sulfate and bicarbonate ion concentrations were calculated and not measured the plot for these ions are not drawn. Calcium and magnesium

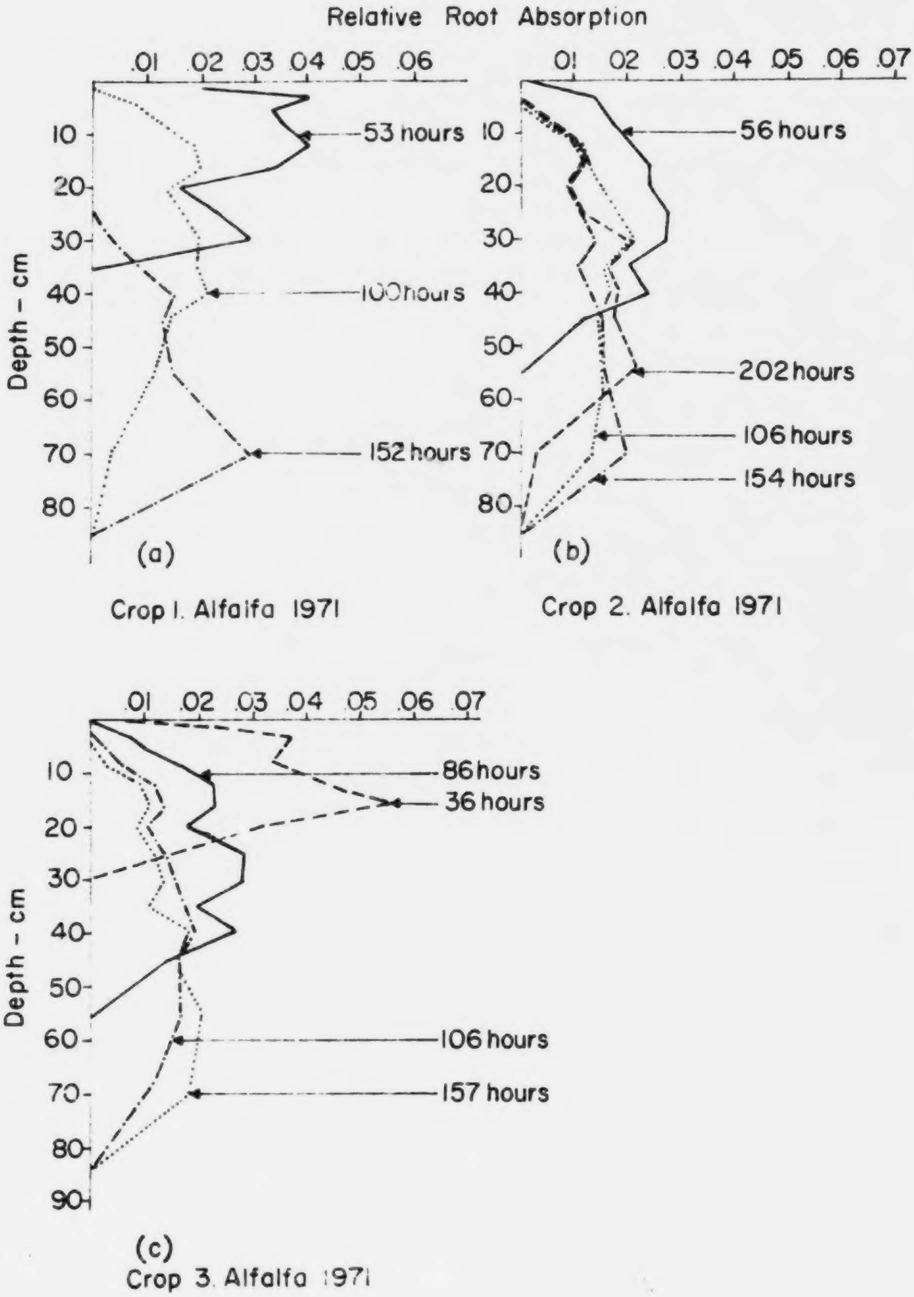

Figure 35. Relative root extraction of alfalfa as a function of time after irrigation and depth.

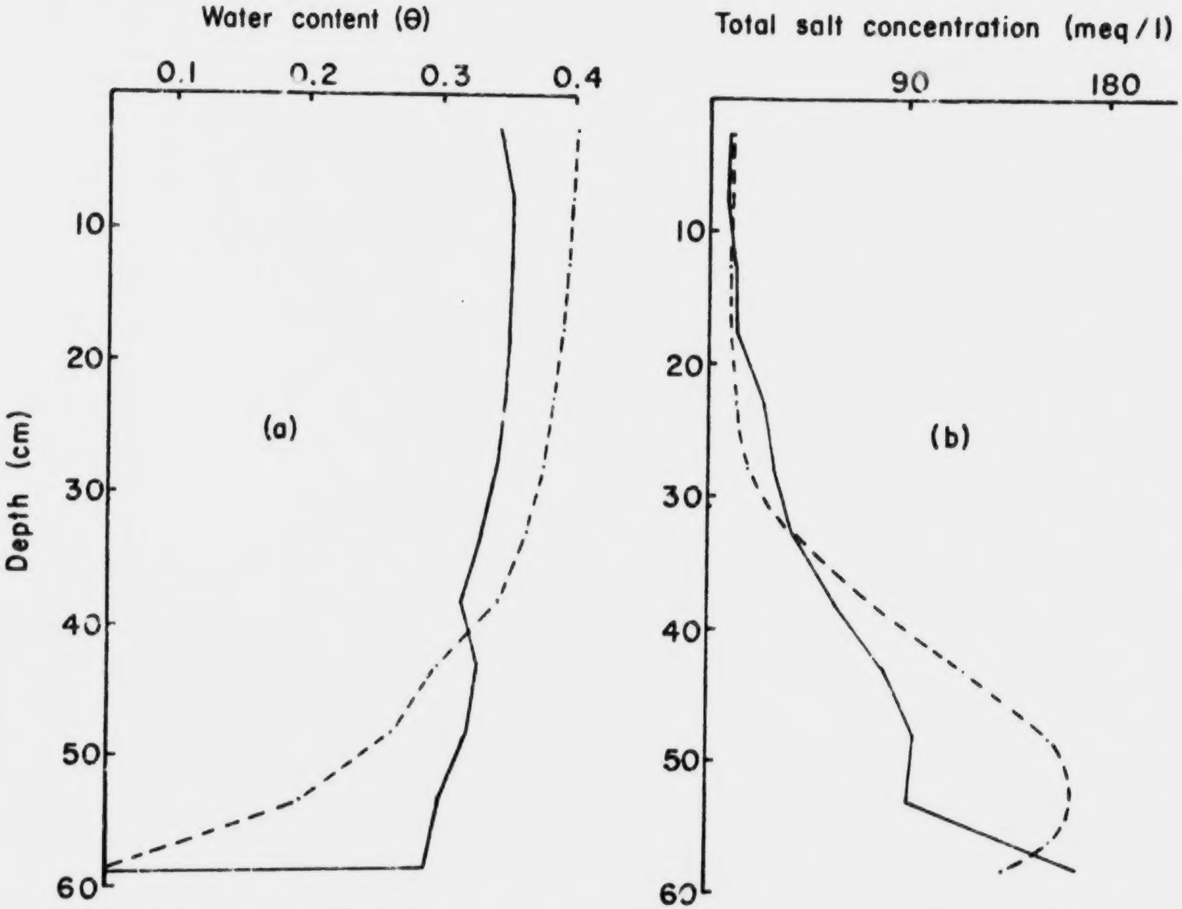

Figure 36. Comparison of predicted (dotted) and measured (solid) water content and total salt concentration profiles for conditions of Case #1.

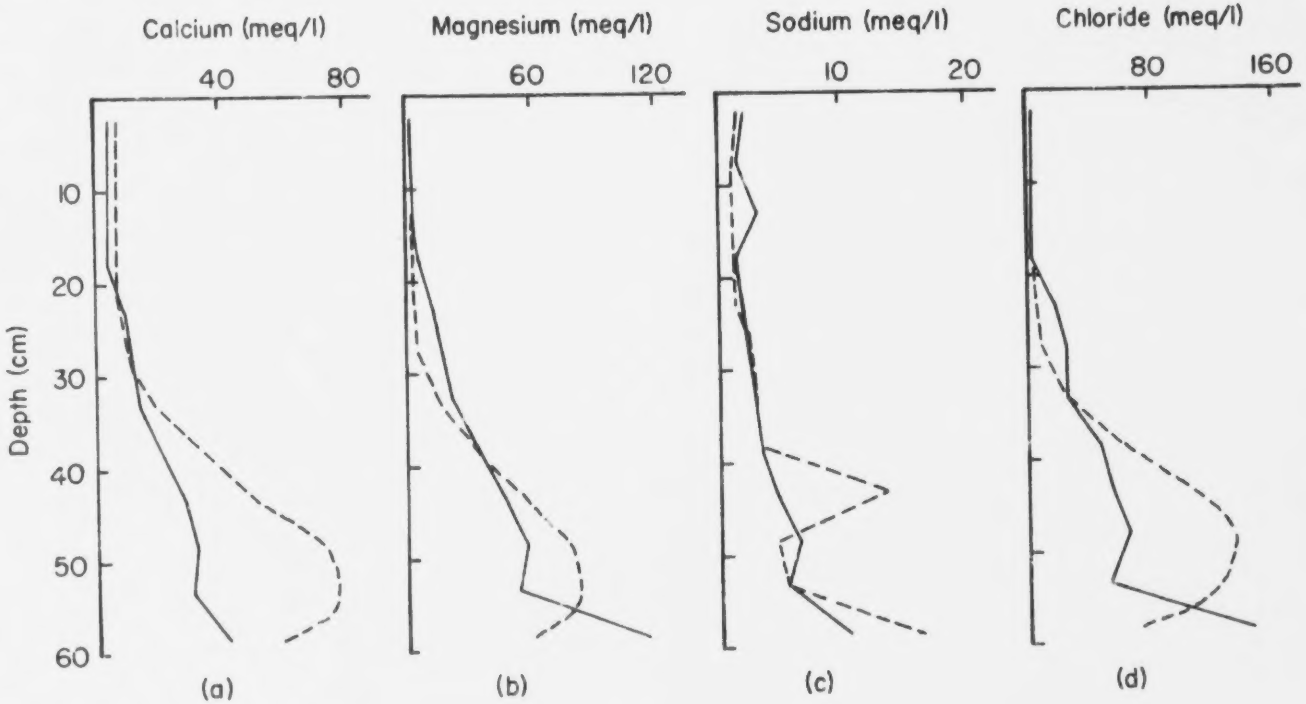

Figure 37. Comparison of predicted (dotted) and measured (solid) ion concentration profiles for conditions of Case #1.

includes the corresponding ions and ion-pairs. Ion-pairs of sodium ions are assumed to be the same as the total sodium concentration.

In general, both the cations and anions followed the same distribution as that of total salts. The concentration of each ion increased with depth and maximum concentration occurred at about 58 cm. Predicted concentration of calcium, magnesium, and sodium seemed to be in close correspondence with the experimental values at low salt concentration. However, there is a significant difference between computed and measured cation concentrations at total salt concentration greater than 45 meq/l. This lack of agreement seems to result from the inadequate description of the cation exchange process at the higher salt concentrations. Since measured and predicted total salts distribution are in reasonable agreement, it is expected that the cations comprising the total salts also follows the same trend. This, however, is not true. The predicted calcium concentration is about 1.5 to 2 times greater than its measured values. Since relative concentration of each cation is controlled by the exchange coefficient, the above differences seems to be due to inadequate information concerning exchange coefficients.

It has been assumed in this study that a given exchange coefficient-total salt concentration relationship holds at all levels of salt concentration. This assumption is not necessarily true. Since concentration of each cation at the end of infiltration is affected by the composition of solution in the early hours of infiltration, the correct values of exchange coefficients seem to be important at high salt concentration in soils.

Another cause for disagreement may be the assumption involving the activity coefficients. It has been assumed that $\gamma_{Ca} = \gamma_{Mg} = \gamma_{SO_4}$. Table values (Robinson and Stokes, 1955) indicate $\gamma_{SO_4} < \gamma_{Ca} < \gamma_{Mg}$ in pure solution. The difference between their values is quite prominent at high ionic strength.

Still another cause for disagreement may be that $Na_2SO_4$, $CaCO_3$, $MgCO_3$, and other complex ion formations are not considered. This may be important because there is an increase in complex ion formation with increase in salt concentration.

Case #2. Three different salts ($CaCl_2$, $MgCl_2$, and NaCl) having a common anion were leached with distilled water. Figure 38 shows the

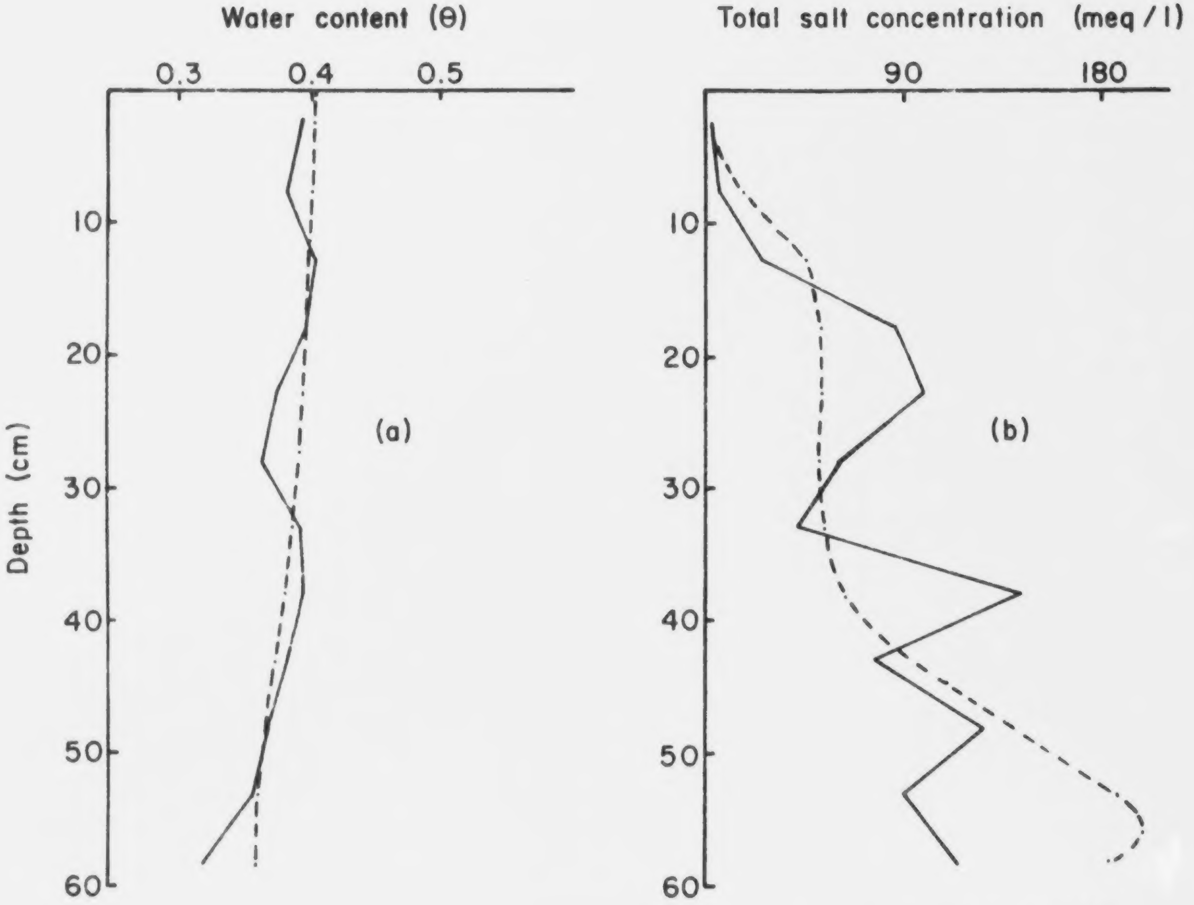

Figure 38. Comparison of predicted (dotted) and measured (solid) water content and total salt concentration profiles for conditions of Case #2.

water content and total salt distribution at the end of 37.6 hours of infiltration. There is good agreement between the observed and the predicted water content distributions. However, the measured total salt concentration is quite different than the predicted values. There is not any regular increase with depth of the measured total salts. There is no well defined depth at which maximum concentrations of total salts occur. This kind of behavior may result from the assumption that all the salts are soluble at initial soil water content. Since the salts were applied in the powder form, it seems that some of the salts were not solublized after the first wetting. Because the water was applied in drops and manually checked for its uniform application at the surface, it is believed that these salts eventually became dissolved at irregular time intervals and led to this type of distribution. There may also be analysis problems or errors unaccounted for.

Figure 39 gives the distribution of individual ions. Measured concentration of almost all the ions follows the same general distribution of total salts. There is poor agreement between the measured and computed values for all the ions. The model at its present stage does not predict adequately the distribution of individual ions in the soil profile.

Case #3. Figure 40 shows the soil moisture and total salt distribution at the end of the experiment where wetting-drying-wetting cycle was followed. Agreement between measured and predicted water content was poor. Measured total salts distribution indicated the presence of two peaks at about 12 and 52 cm depths, while the model predicted a single depth (38 cm) at which maximum concentration occurred. It was expected that all the salts would have moved to the bottom of the column at the end of the second infiltration. As sodium ions (Figure 41c) are the major components contributing to the peak in total salt concentration, at 12 cm depth, it may be that all the NaCl salt added before the second irrigation apparently did not dissolve immediately after irrigation, as is assumed in the model.

## Salt Model-Field Experiment

The detailed salt model was also tested under field conditions at the Hullinger farm near Vernal, Utah. Water movement and, thus, the salt movement due to the presence of roots was also considered. In order to avoid the complexity arising due to layered soil, the soil profile was assumed to have uniform properties throughout. Presence

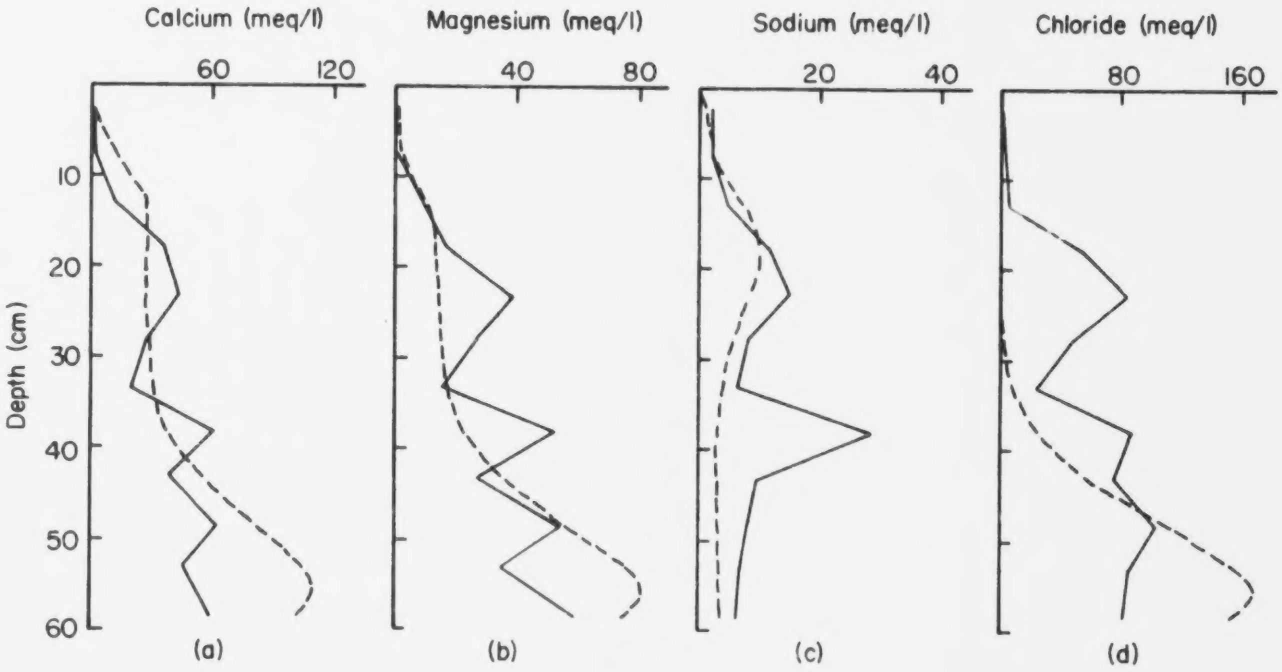

Figure 39. Comparison of predicted (dotted) and measured (solid) ion concentration profiles for conditions of Case #2.

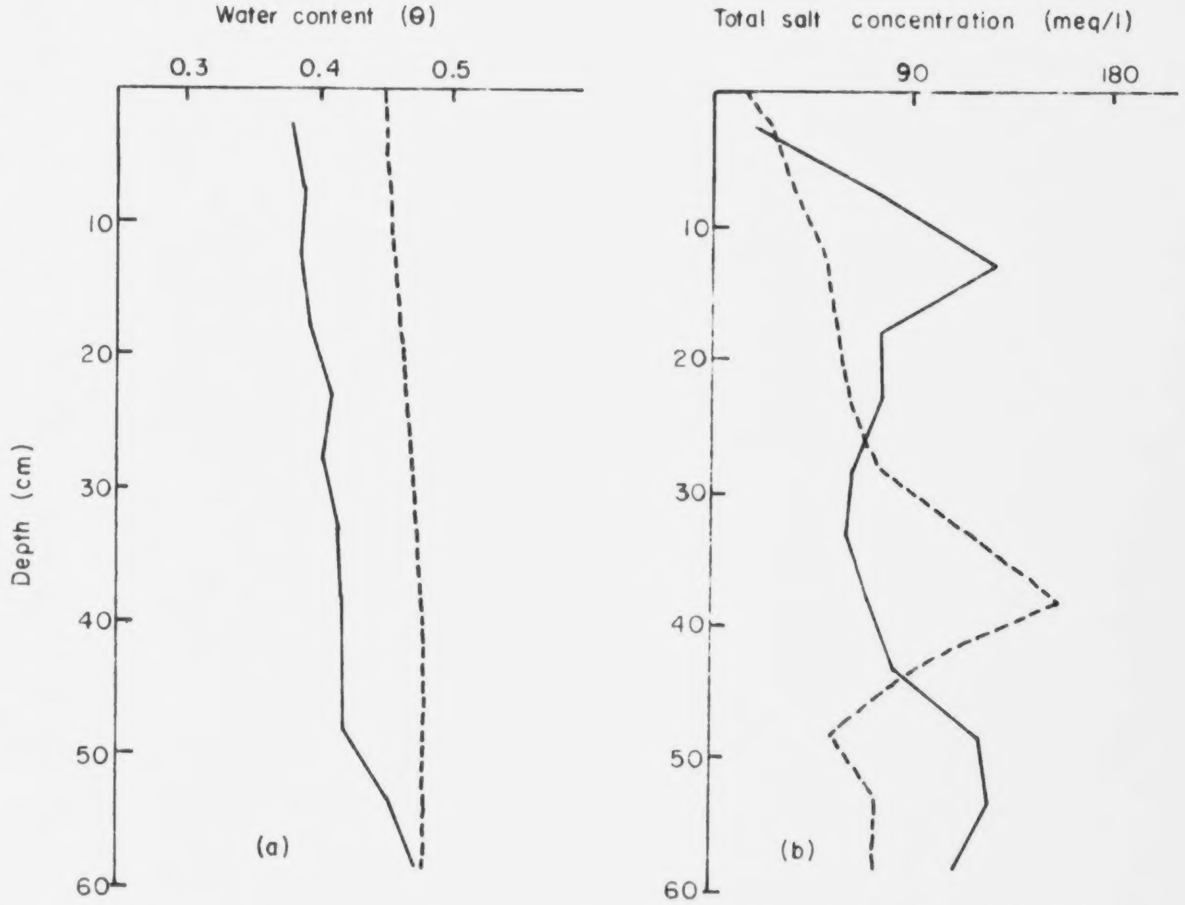

Figure 40. Comparison of predicted (dotted) and measured (solid) water content and total salt concentration profiles for conditions of Case #3.

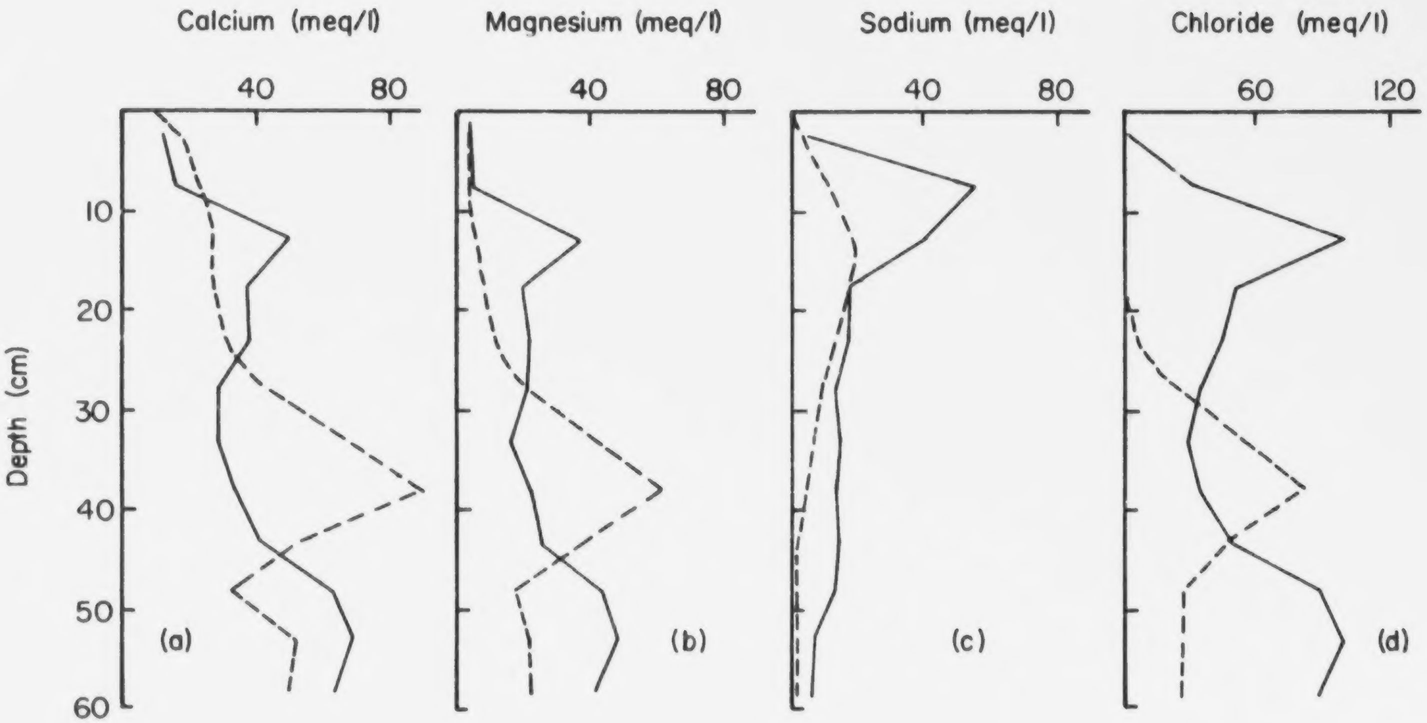

Figure 41. Comparison of predicted (dotted) and measured (solid) ion concentration profiles for conditions of Case #3.

of gypsum was considered in the initial conditions below 30 cm depth. The model was tested over a period of two drying and wetting cycles. Hysteresis in the hydraulic properties was ignored. Comparison of the predicted and measured values was made at three different times in the cycle. Since no measurements of individual ions were made on the solution samples at field water content, an approximate method was used to arrive at the concentrations from the saturation extraction analysis. The method involves the assumption that the individual ion concentration changes in the same proportion with changing water content as does the electrical conductivity of the solution. This assumption may not be exactly valid for complex ions and ions which react with the soils. Since chloride ions do not interact with the soil, it is expected that the given assumption holds good for chloride.

Figure 42 presents the water content distribution at three different times during the cycle. There is good correspondence between the measured and predicted values on the first (Figure 42a) and the third (Figure 42c) samplings. The poorest agreement is shortly after irrigation (Figure 42b) where the computed water flow is not distributed within the soil as much as the measured. This has been discussed earlier.

Electrical conductivities of solution at field water content and saturation extract are plotted in Figure 43. The ratio of the two values was used to correct the saturation extract analysis to get ion concentration (Figures 44-47) at field water content. For the third sampling (Figure 44c), the predicted values closely relate to the corrected total salt concentration. Since the saturation extract analysis represented an average of 30 cm depth, the corrected concentrations are also represented by histograms. The depth at which the maximum concentration occurs is the same in measured and predicted distributions.

Figures 45, 46, and 47 give the individual cation distribution. Measured calcium concentrations are generally less than the predicted values, while the reverse is true for sodium and magnesium concentrations. These differences seem to result from the assumption that cation concentration changes in the same proportion as does the EC of the solution. Since the preference of exchanger for the ions of higher valence increased with dilution of the solution (Helfferich, 1962) it is expected that the proportionate increase in calcium and magnesium be more than in sodium. The approximation used to get the ion concentration at field water content, however, assumes the same dilution effect for all the cations.

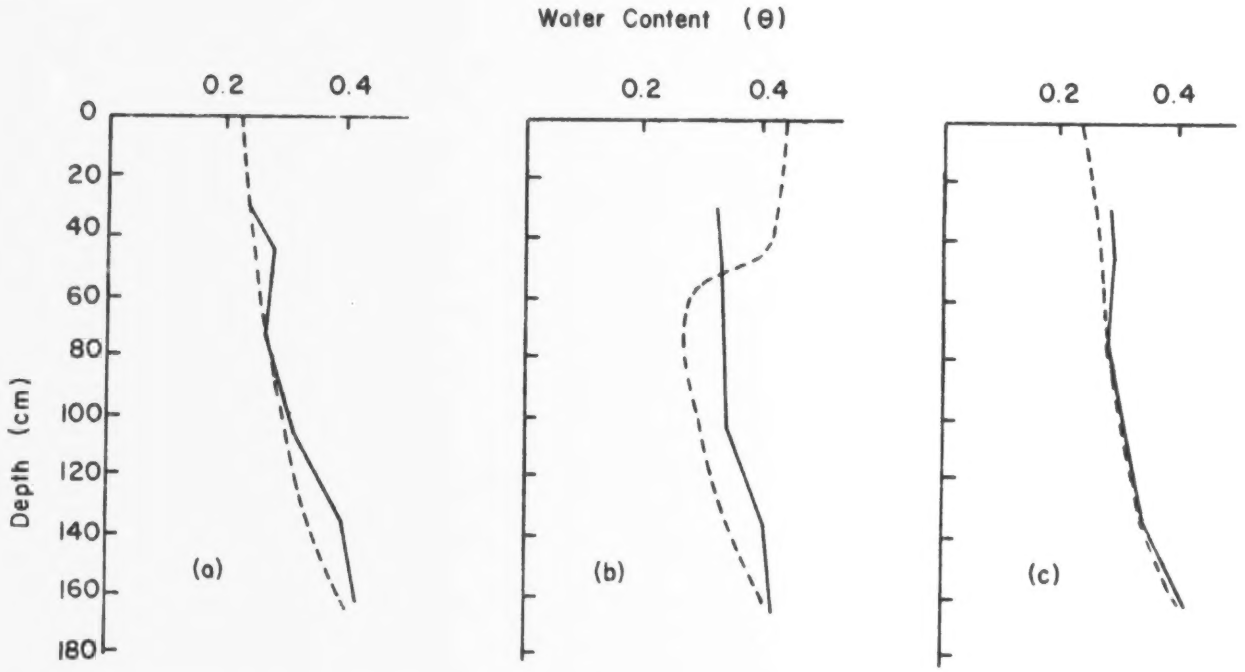

Figure 42. Comparison of predicted (dotted) and measured (solid) water content profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs.

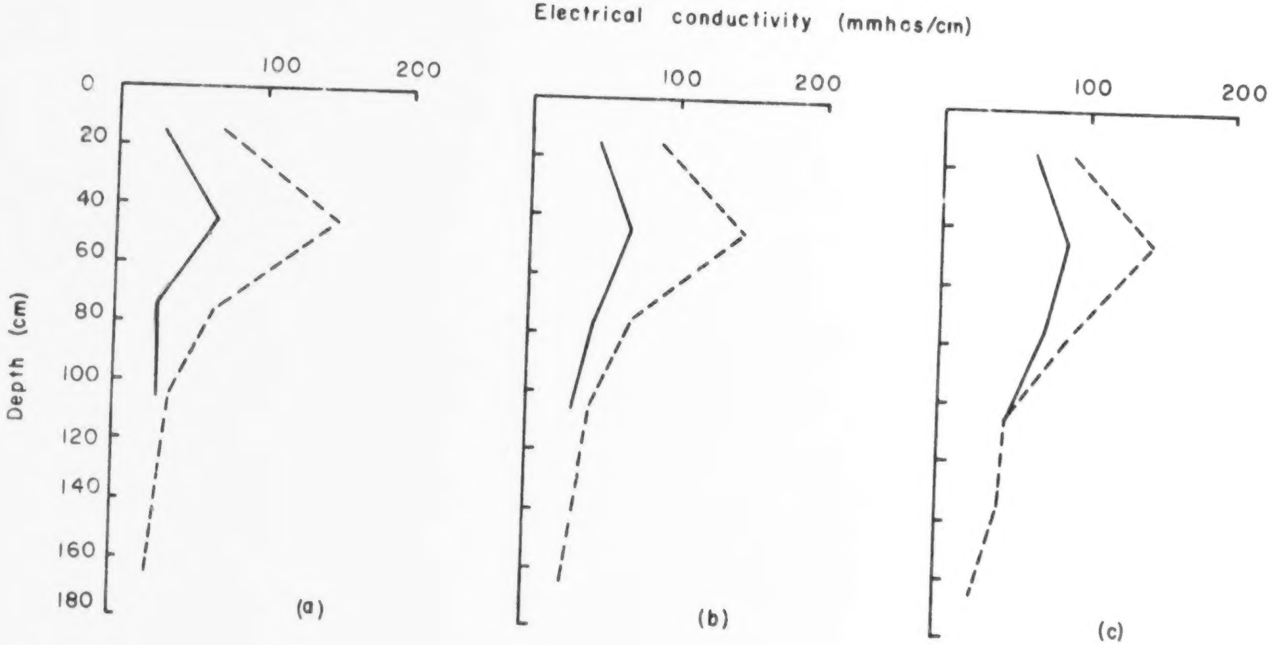

Figure 43. Comparison of saturation extract (solid) and soil solution (dotted) electrical conductivity profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs.

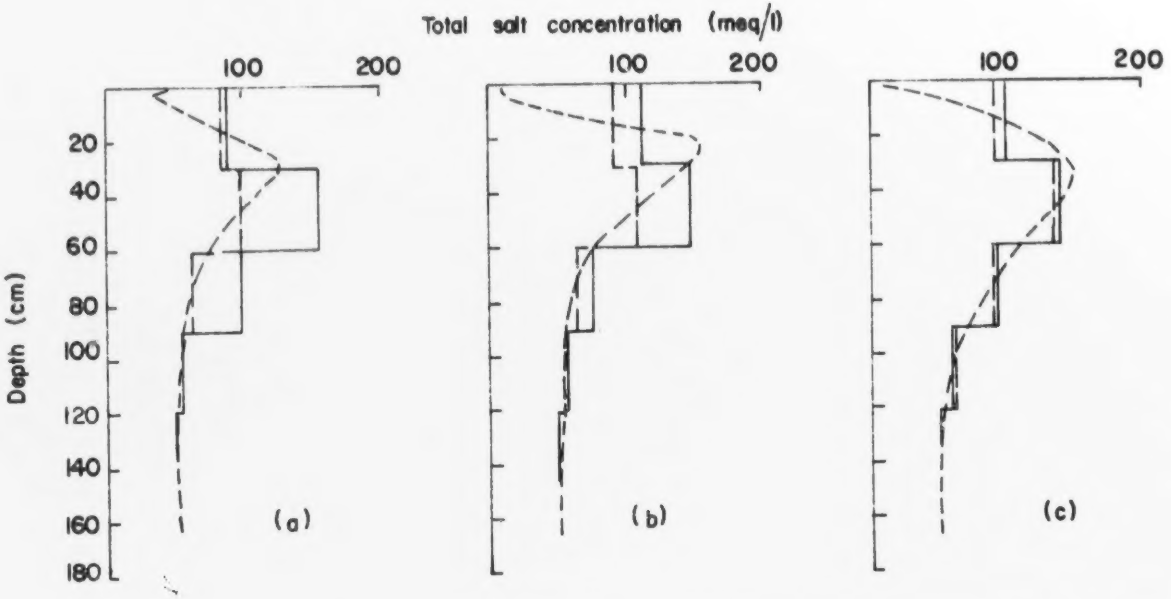

Figure 44. Comparison of predicted (dotted) and measured (solid) total salt concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown.

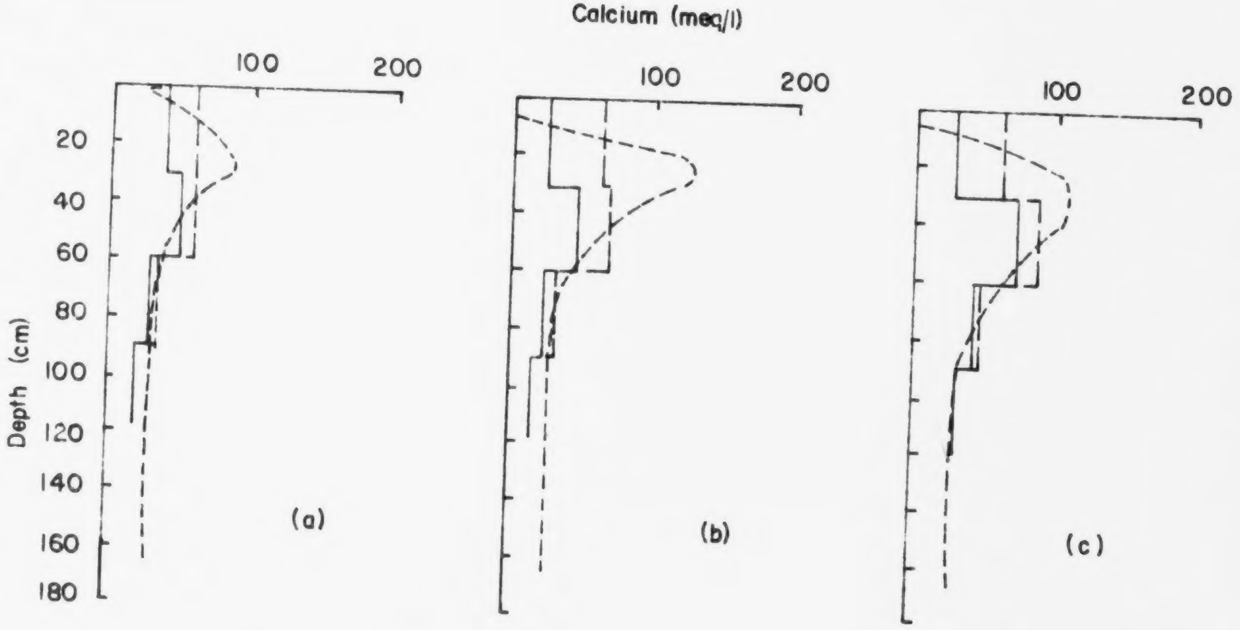

Figure 45. Comparison of predicted (dotted) and measured (solid) calcium concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown.

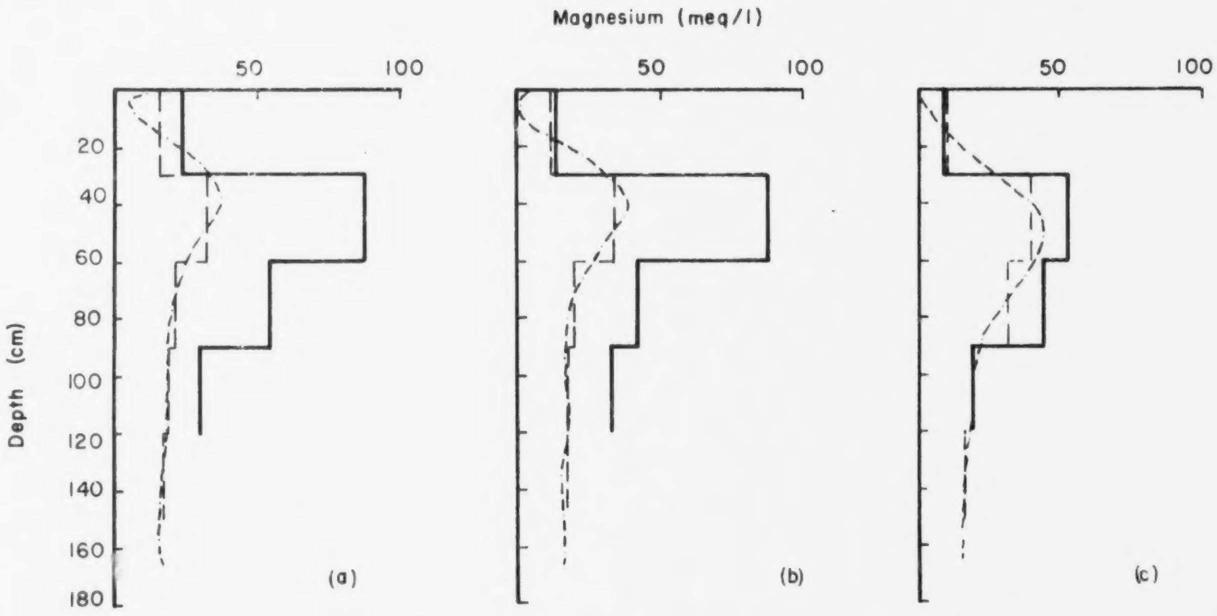

Figure 46. Comparison of predicted (dotted) and measured (solid) magnesium concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown.

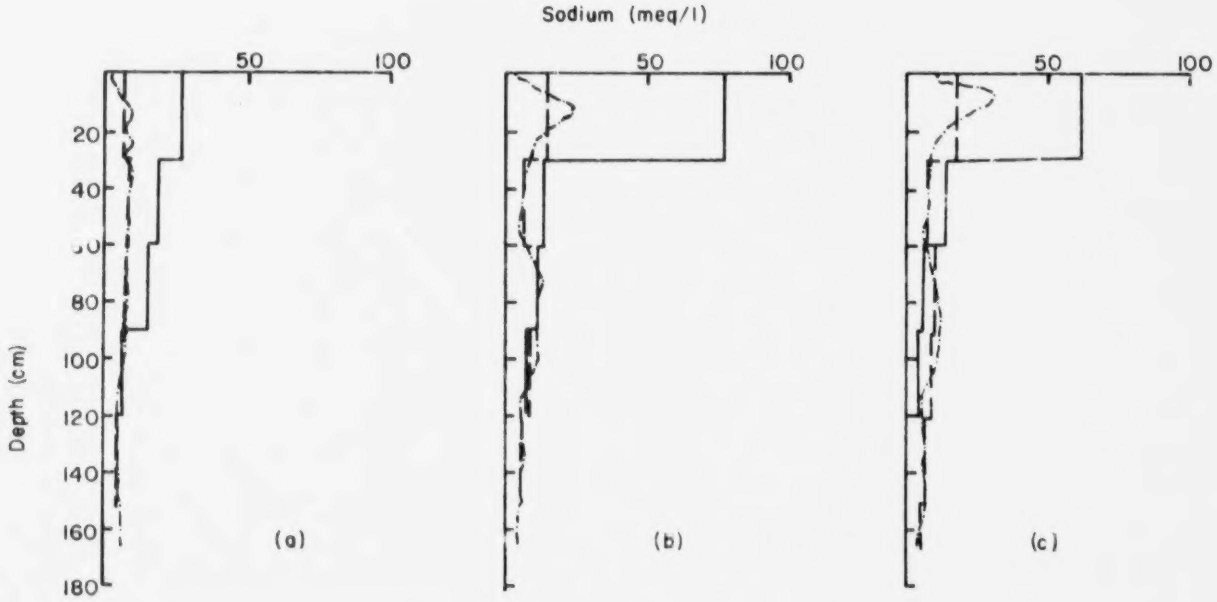

Figure 47. Comparison of predicted (dotted) and measured (solid) sodium concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown.

Sodium concentration measured in the saturation extract is also higher than the computed values while the opposite is true for the magnesium and calcium concentrations. Since the area under total salt curves is about the same for both measured and predicted distribution, the relative concentration of cations depends upon the exchange coefficients as discussed previously in Case #1.

Chloride concentrations are plotted in Figure 48. It follows about the same distribution as that of total salts. The agreement between the measured and predicted chloride concentration is fair. However, the depth at which the maximum chloride ion concentration occurs is deeper in the measured than in the predicted distribution. This lack of agreement may be due to the discontinuous nature of measured chloride distribution curve.

Figure 49 gives the depth and salt concentration of the drainage water during this experiment. Since no measurements were made, only computed values are plotted. It shows the capability of this model to provide this kind of information, which is useful in devising a scheme for quality control of irrigation return flow.

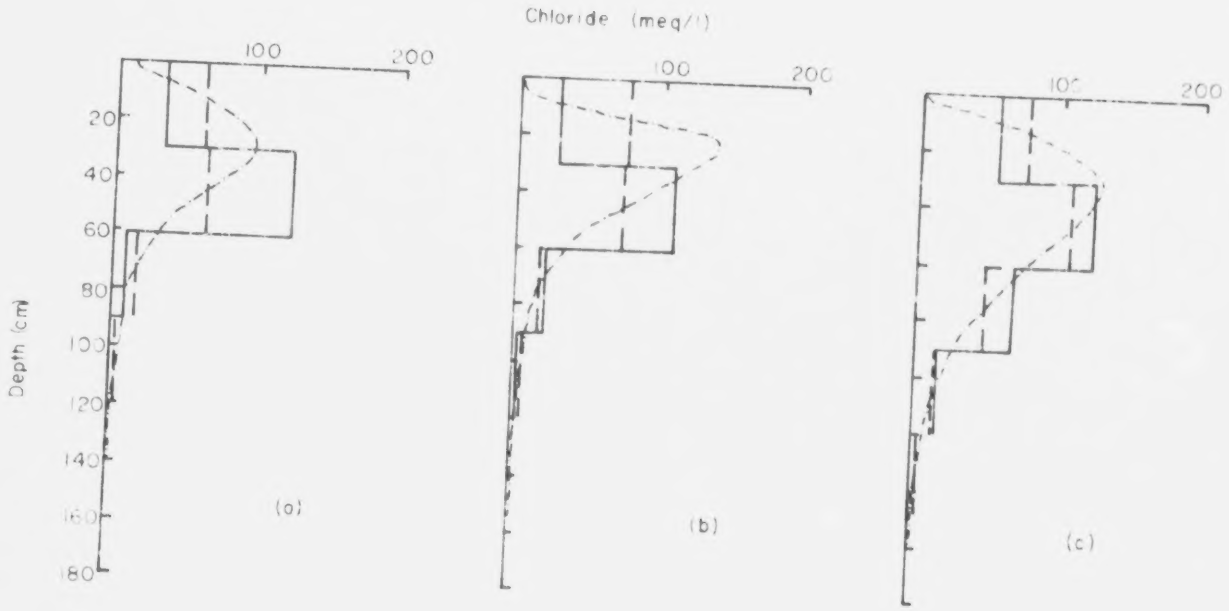

Figure 48. Comparison of predicted (dotted) and measured (solid) chloride concentration profiles for alfalfa (a) 324 hrs, (b) 339 hrs, and (c) 627 hrs. Both the predicted histograms and continuous curves are shown.

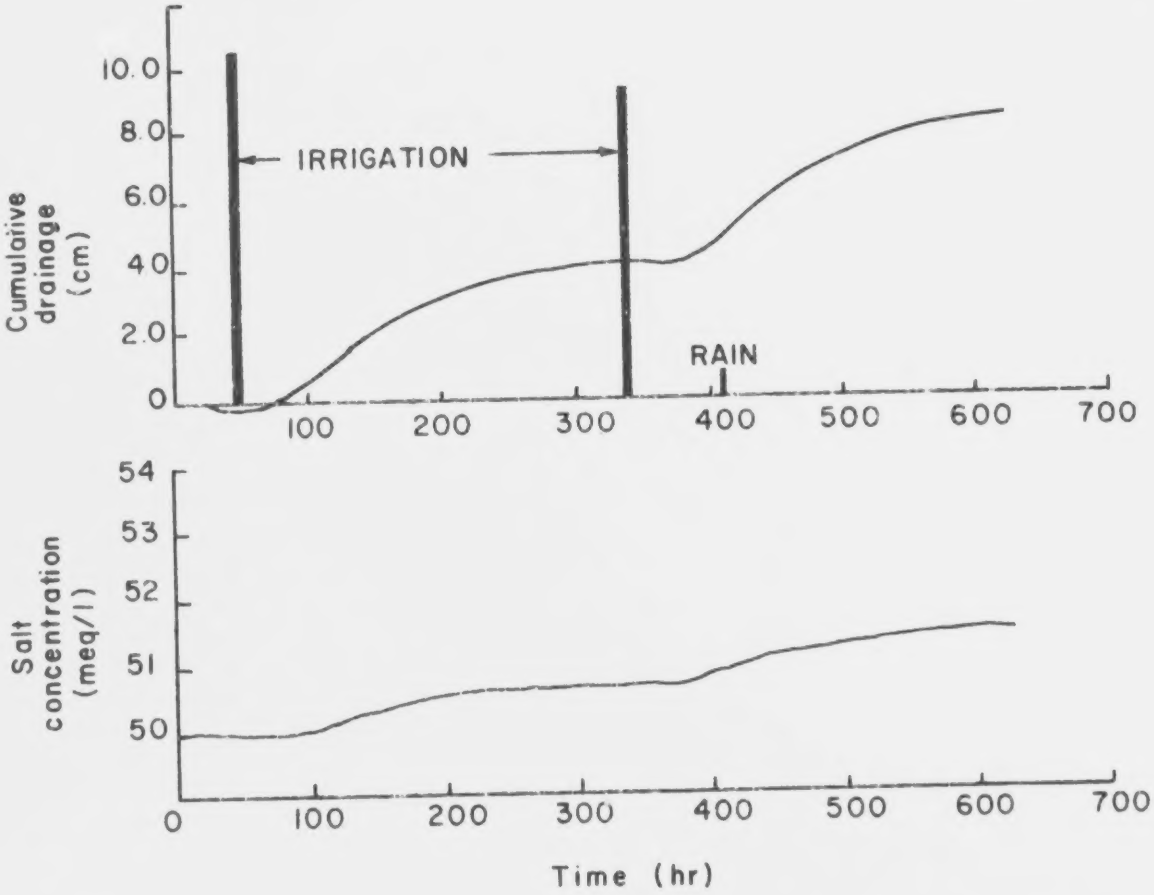

Figure 49. Predicted drainage and salt concentration of the drainage water over a period of 627 hrs.

# SECTION VII

# USE OF MODELS FOR IRRIGATION MANAGEMENT

Irrigation management for water quality control has many important facets. The major idea upon which the research work of this report is based is that the soil profile may be used as a salt storage reservoir. The goal of irrigation management would be to control the releases from this salt reservoir while also producing agricultural crops economically. The simplified model only was tested in this section although the detailed model could have been used at a much higher cost in computer time.

## Irrigation Water Quality

The quality of the irrigation water supply influences good irrigation management practices. The question arises as to whether the seasonal average concentration of salts in applied irrigation water would be adequate for modeling or whether the concentration must be accurately known for each irrigation. The simplified model (prediction version) was used to calculate the depth of water to be applied for each irrigation (14-day interval) of the season such that $EC_s$ for each soil layer did not exceed the "concentration constraints" of Table 27. The EC of all irrigation water was 1.8 mmho/cm. Results were compared with two other methods of calculation.

First, the prediction version was operated from irrigation to irrigation, treating each irrigation interval as a season, so that EC of irrigation water could vary according to a generally increasing function of time (Figure 50) or a generally decreasing function (Figure 51). The seasonal average EC of irrigation water was 1.8 mmho/cm in all cases. All other conditions of the problem remained the same including the concentration constraints. Results are given in Tables 28, 29, and 30. The results of the seasonal average case were nearly the same as those for the case in which the concentration increased. Only the difference between the predictions of salt leaving the root zone (Table 29) may be significant. However, there is a significant difference between the average concentration case and the decreasing concentration case for all three output parameters (depth of irrigation water, salt leaving the root zone, and leaching water). If it is necessary to predict the amount

Preceding page blank

of salt leaving the root zone for each irrigation, it is obvious from the comparison of the three cases in each table that the use of the seasonal average is not adequate.

Table 27. Concentration constraints for each soil layer used in hypothetical problem.

| Soil Layer | Concentration Constraint (mmho/cm) | Soil Layer | Concentration Constraint (mmho/cm) |
|---|---|---|---|
| 1 | 4.0 | 6 | 6.0 |
| 2 | 4.4 | 7 | 6.4 |
| 3 | 4.8 | 8 | 6.8 |
| 4 | 5.2 | 9 | 7.2 |
| 5 | 5.6 | 10 | 7.6 |

Table 28. Depth in inches of water applied during each irrigaticn.

| Irrigation Number | Seasonal Average | Increasing Concentration | Decreasing Concentration |
|---|---|---|---|
| 1 | 5.83 | 5.83 | 5.83 |
| 2 | 2.38 | 2.38 | 6.37 |
| 3 | 5.37 | 5.48 | 6.68 |
| 4 | 6.04 | 4.81 | 5.81 |
| 5 | 4.95 | 4.57 | 4.62 |
| 6 | 4.95 | 5.69 | 5.26 |
| 7 | 4.60 | 5.73 | 4.51 |
| 8 | 4.08 | 3.66 | 3.84 |
| TOTAL | 38.22 | 38.15 | 42.92 |

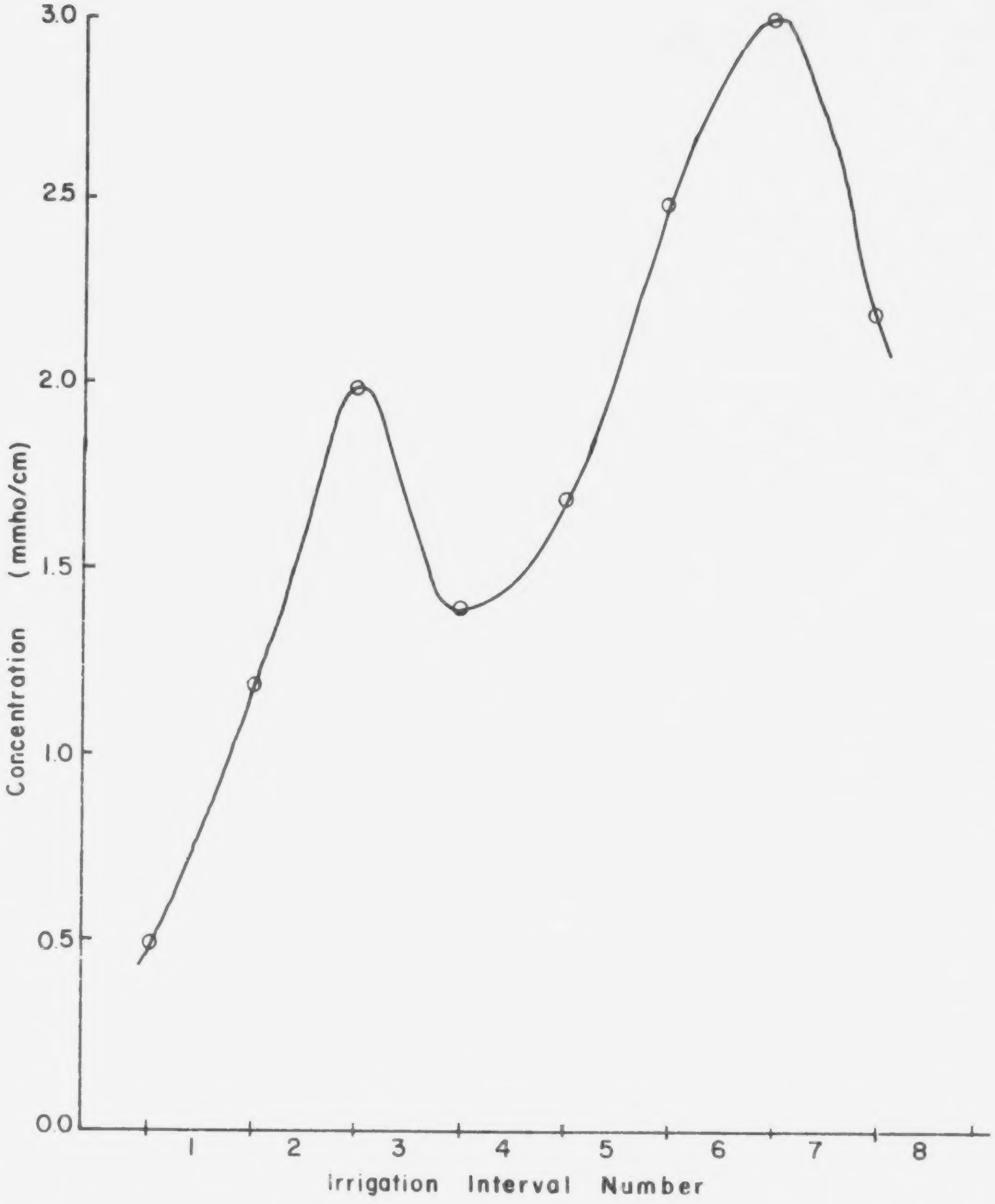

Figure 50. Generally increasing concentrations of irrigation water in mmho/cm during the growing season. (The circled values are the concentrations at each irrigation).

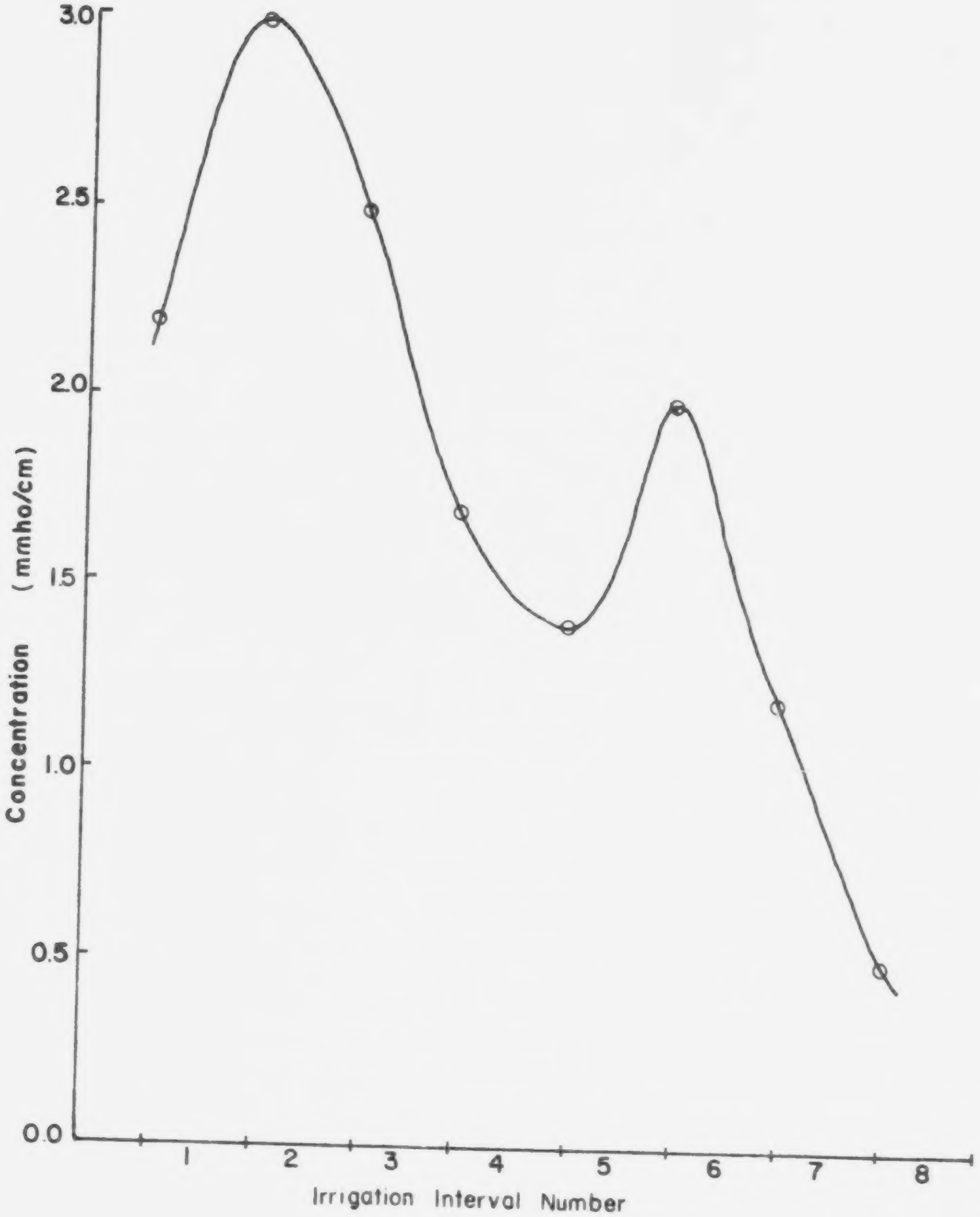

Figure 51. Generally decreasing concentrations of irrigation water in mmho/cm during the growing season. (The circled values are the concentrations at each irrigation).

Table 29. Salt leaving the root zone in tons per acre for each irrigation.

| Irrigation Number | Seasonal Average | Increasing Concentration | Decreasing Concentration |
|---|---|---|---|
| 1 | .00 | .00 | .00 |
| 2 | .00 | .00 | 1.21 |
| 3 | .57 | .53 | 1.07 |
| 4 | .71 | .21 | .62 |
| 5 | .23 | .07 | .10 |
| 6 | .43 | .69 | .58 |
| 7 | .52 | .99 | .48 |
| 8 | .52 | .27 | .40 |
| TOTAL | 2.98 | 2.76 | 4.46 |

Table 30. Depth in inches of leaching water required for each irrigation.

| Irrigation Number | Seasonal Average | Increasing Concentration | Decreasing Concentration |
|---|---|---|---|
| 1 | .00 | .00 | .00 |
| 2 | .00 | .00 | 3.99 |
| 3 | 1.87 | 1.98 | 3.18 |
| 4 | 1.98 | .75 | 1.75 |
| 5 | .60 | .22 | .27 |
| 6 | .97 | 1.71 | 1.28 |
| 7 | 1.08 | 2.21 | .99 |
| 8 | 1.05 | .63 | .82 |
| TOTAL | 7.55 | 7.50 | 12.28 |

The second method of calculation for comparison was to use the depth for each irrigation calculated by the seasonal average EC and the value of EC of each irrigation from Figures 50 and 51 as input to the evaluation version. Results are shown in Tables 31 and 32. If it is assumed that the values in Table 31 for increasing concentration and decreasing concentration were actual, then attempting to model these conditions with the seasonal average EC of irrigation water would result in overpredicting salt discharge in the first case and underpredicting it in the second case. Table 32 shows $EC_s$ of each soil layer at the end of each irrigation interval whenever $EC_s$ exceeded the concentration constraints of Table 27.

Table 31. Salt leaving the root zone in tons per acre for each irrigation when the depth of water applied is input.

| Irrigation Number | Seasonal Average | Increasing Concentration | Decreasing Concentration |
|---|---|---|---|
| 1 | .00 | .00 | .00 |
| 2 | .00 | .00 | .00 |
| 3 | .57 | .50 | .62 |
| 4 | .71 | .57 | .81 |
| 5 | .23 | .18 | .27 |
| 6 | .43 | .35 | .49 |
| 7 | .52 | .44 | .58 |
| 8 | .52 | .47 | .57 |
| TOTAL | 2.98 | 2.51 | 3.34 |

Admittedly, this exercise was brief and more modeling of various situations is needed. However, when EC of irrigation water fluctuates substantially, the actual EC of applied water for each irrigation instead of the seasonal average should be used in modeling salt discharges.

Table 32. Concentration of the soil solution in millimhos per centimeter after each irrigation interval when the computed concentration exceeded the critical concentration.

| Soil Layer | Concentration Constraint (mmho/cm) | Irrigation Interval Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 4.00 | | 5.91 | 5.63 | | | 4.44 | 4.75 | |
| 2 | 4.40 | | 4.92 | 5.16 | | | | 4.63 | |
| 3 | 4.80 | | | 5.35 | | | | 4.86 | |
| 4 | 5.20 | | | 5.42 | | | | | |
| 5 | 5.60 | | | 5.71 | | | | | |
| 6 | 6.00 | | | | | | | | 6.05 |
| 7 | 6.40 | | | | 6.45 | 6.88 | 6.63 | | 6.53 |
| 8 | 6.80 | | | | | 7.60 | 7.65 | 7.19 | 6.96 |
| 9 | 7.20 | | | | | 7.55 | 8.04 | 7.94 | 7.54 |
| 10 | 7.60 | | | | | | 7.70 | 8.05 | 8.02 |

Note: Values left of the double line are for the decreasing concentration case, and those right of the double line are for the case of increasing concentration.

## Irrigation Timing

In order to demonstrate the utility of the models for irrigation management, 24 separate problems were solved with the simplified model (prediction version). The 24 problems were designed to include all combinations of 2 values of irrigation water EC, 3 curves of initial $EC_s$, and 4 curves of concentration constraints. All other data were the same for all problems and are shown in Examples 1 and 2, Appendix A. Table 33 gives the values used for irrigation water EC, initial $EC_s$, and concentration constraints. All 24 problems had the same total initial salt content of 1.92 tons/acre, but its distribution in the soil profile varied. The irrigation season was 121 days long. The 121-st day was included to make a valid end point for comparison. An irrigation occurred on the 121-st day with no subsequent ET. Thus all computer runs for the different intervals between irrigations began with the same moisture deficit and ended with the soil moisture at $\theta_{fm}$. For the 121-day period, intervals between irrigations of 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 days were used. A 24-day interval dried the soil below the wilting point somewhere in the season and hence was not acceptable.

Figures 52 and 53 show the results of problems ACF and BCF, respectively (see footnote, Table 33) at the end of the 121-day season as a function of the interval between irrigations (irrigation frequency). Similar figures for the other problems are included in Appendix C (Figures 60 - 81). From Figure 52 for irrigation water EC equal to 1.5 mmho/cm, it is seen that as the irrigation interval increases, the leaching water tends toward a nearly constant value. Coincident with the nearly constant leaching water, the salt removed from the root zone tends to level off as does the total water applied. The salt remaining in the profile continues to decrease although not very significantly. The important aspect from a management standpoint is that there is considerable range of irrigation frequencies over which seasonal results do not change significantly. Figure 53, for irrigation water EC equal to 2.0 mmho/cm, shows similar results. Although the curves begin high for short intervals between irrigations, they tend to level off over a considerable range of irrigation frequencies.

Figures 54 and 55 show the results of problems ACF and BCF, respectively, for each irrigation during the season with irrigation intervals of 8 and 20 days. Both of these irrigation frequencies are on the level parts of the curves of Figures 52 and 53. Figures 54 and 55 show the trend of longer intervals releasing salt from the soil profile earlier in the season than the shorter intervals.

Table 33. Values of irrigation water, EC, initial $EC_s$, and concentration constraints used in simplified model for solution of 24 problems. (mmho/cm)

| Irrigation Water EC | |
|---|---|
| A* | B |
| 1.5 | 2.0 |

| | Initial $EC_s$ | | | Concentration Constraints | | | |
|---|---|---|---|---|---|---|---|
| Soil Layer | C | D | E | F | G | H | I |
| 1 | 3.68 | 1.38 | 5.98 | 6.00 | 5.00 | 4.00 | 3.00 |
| 2 | 2.83 | 1.38 | 4.28 | 6.00 | 5.18 | 4.36 | 3.55 |
| 3 | 2.45 | 1.47 | 3.43 | 6.00 | 5.36 | 4.73 | 4.09 |
| 4 | 2.30 | 1.65 | 2.95 | 6.00 | 5.55 | 5.09 | 4.64 |
| 5 | 2.16 | 1.80 | 2.53 | 6.00 | 5.73 | 5.45 | 5.18 |
| 6 | 2.16 | 1.80 | 2.53 | 6.00 | 5.91 | 5.82 | 5.73 |
| 7 | 2.04 | 2.16 | 1.93 | 6.00 | 6.09 | 6.18 | 6.27 |
| 8 | 1.94 | 2.26 | 1.61 | 6.00 | 6.27 | 6.55 | 6.82 |
| 9 | 1.94 | 2.26 | 1.61 | 6.00 | 6.45 | 6.91 | 7.36 |
| 10 | 1.75 | 2.45 | 1.05 | 6.00 | 6.64 | 7.27 | 7.91 |
| 11 | 1.67 | 2.53 | 0.82 | 6.00 | 6.82 | 7.64 | 8.45 |
| 12 | 1.60 | 2.60 | 0.60 | 6.00 | 7.00 | 8.00 | 9.00 |

*The letters A through I are used to designate the particular values used; i.e., problem ACF uses column A, C, and F, of this table

The above results indicate possibilities for control of drainage water quality as it leaves the root zone. On a valley-wide basis two possible alternative modes of management might be: (1) Irrigate different farms at different frequencies so as to maintain a nearly constant quality of drainage effluent during the season; or (2) Irrigate all farms at nearly the same frequency so as to peak the salt discharge at some convenient time. This peak of salt discharge might be diverted to an evaporation basin or other suitable salt sink in areas where man-made drainage systems are extensive.

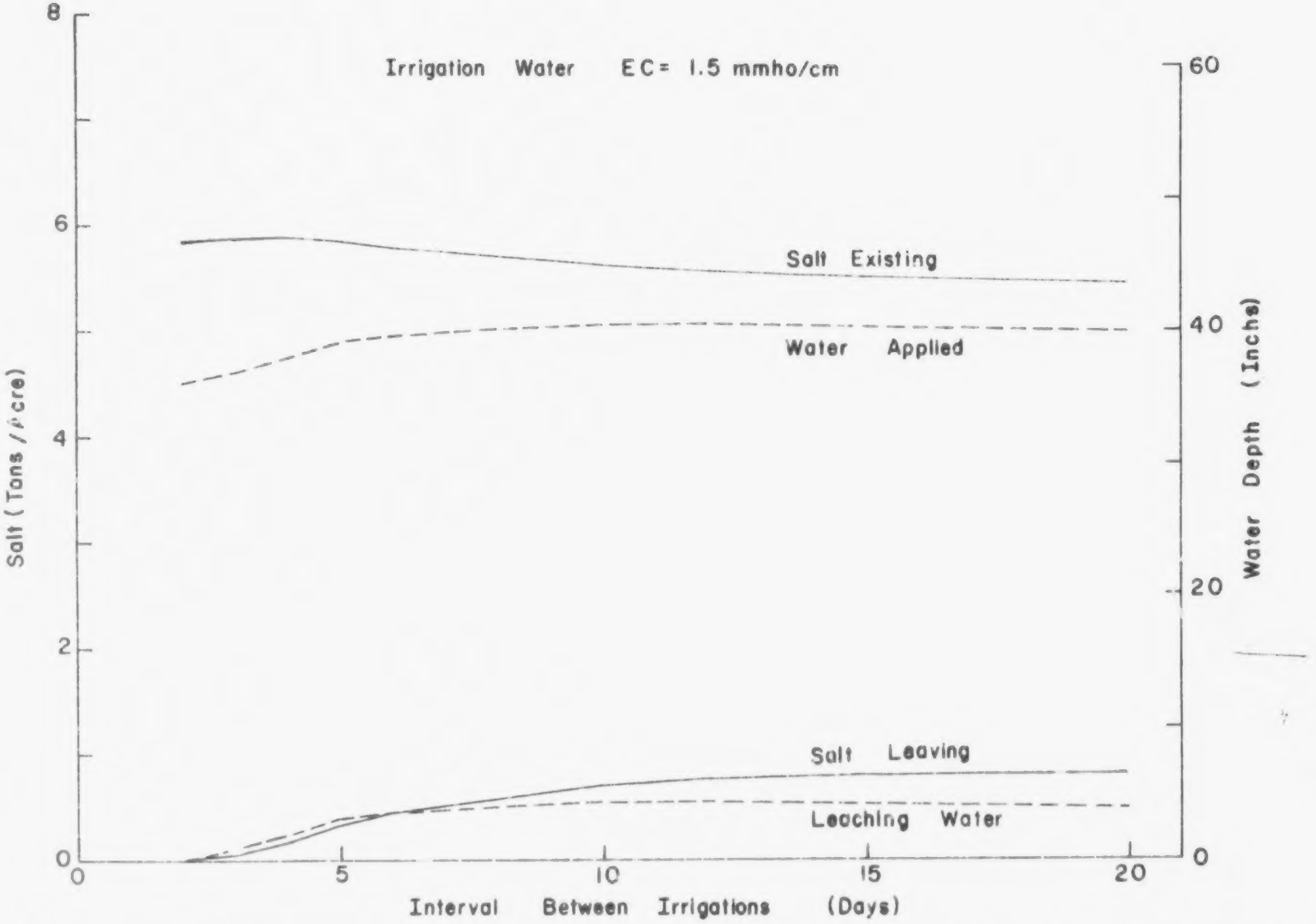

Figure 52. Season totals of salt existing, salt leaving, water applied, and leaching water as functions of irrigation frequency for problem ACF.

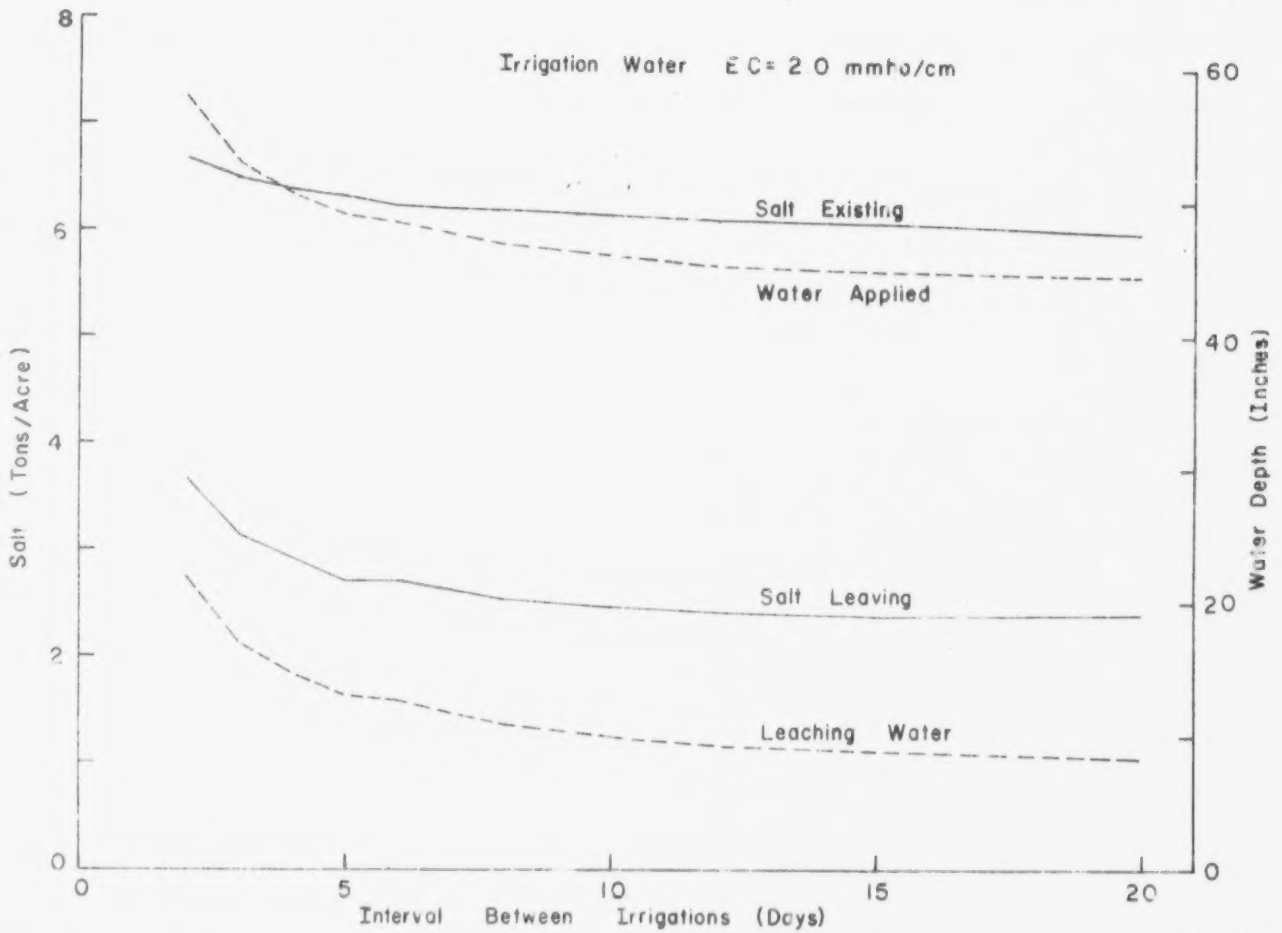

Figure 53. Season totals of salt existing, salt leaving, water applied, and leaching water as functions of irrigation frequency for problem BCF.

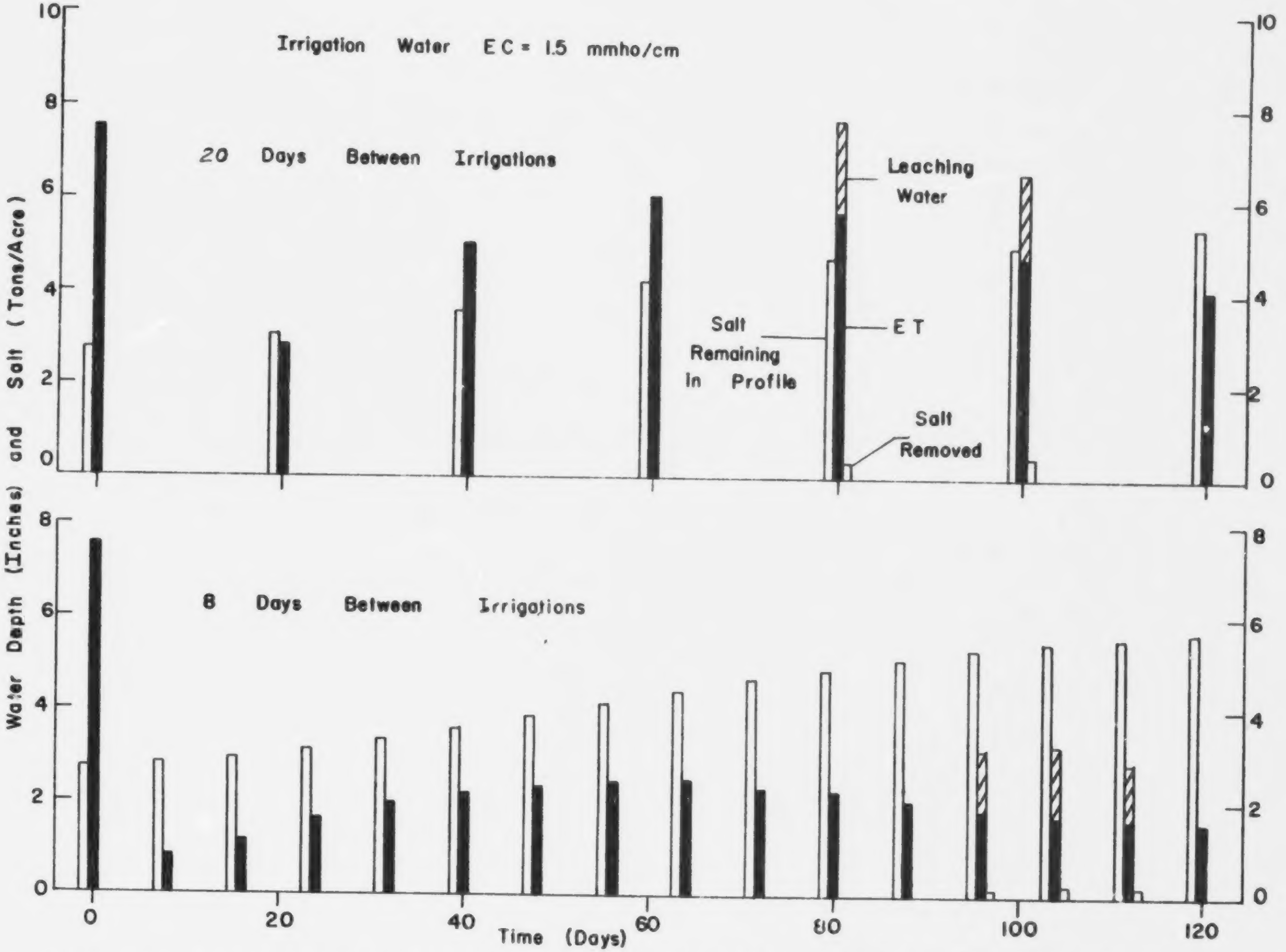

Figure 54. Results of problem ACF for each irrigation of the season for 8 and 20 days between irrigations.

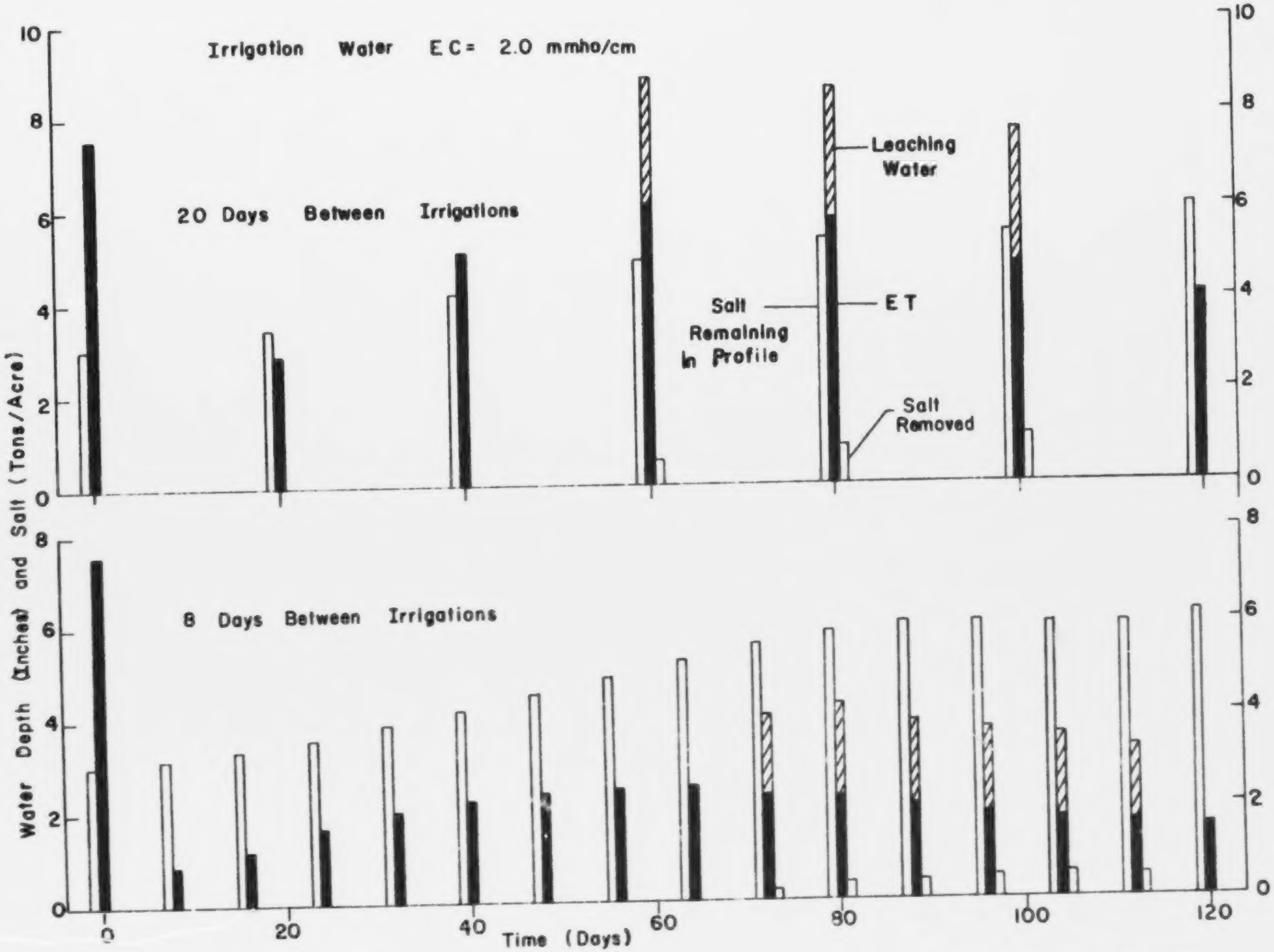

Figure 55. Results of problem BCF for each irrigation of the season for 8 and 20 days between irrigations.

More research is needed on how to use the models to develop irrigation management practices which will exercise control over quality of irrigation return flow. The examples presented indicate that results are very site-specific and that broad generalizations are difficult if not impossible to make.

Considerable further work is needed in order to predict the fate of the water after it leaves the root zone until it arrives as return flow in the stream or groundwater body. Study must be given to factors such as residence times, travel paths, degree of mixing with groundwater underflow before full evaluation can be made of managing irrigation to achieve water quality control. It is evident from the work on control in the root zone that very sophisticated irrigation systems capable of precise control over depth and timing of irrigation are necessary. Such systems do exist but are rather expensive. For full benefit efficient drainage systems having short residence times and capable of flexible control are also deemed necessary.

# SECTION VIII

## SUMMARY

Two basically different models were developed for predicting the movement of water and salt through the root zone of growing crops. The two were termed "simplified" and "detailed" models for the purposes of this report.

### Simplified Model

The simplified model is basically a unit cell mixing model. Long-term drainage and upward movement of water are ignored. Water entering a given soil layer increases its moisture content to a maximum ($\theta_{fm}$) and the excess water passes on to the next lower layer. Further loss of water from the layer is limited to the extraction by ET during the interval following the irrigation. The salt movement is described in terms of the leaching factor, defined as the mass of salt leaving the layer divided by the sum of the mass existing prior to irrigation plus the mass entering.

The prediction version of the simplified model is based upon the concept of temporarily storing salt in the soil profile and leaching only when necessary to prevent the concentration of salt in the soil solution from exceeding a pre-set concentration constraint. This version determines the depth of water to be applied for each irrigation for a given irrigation water quality and irrigation frequency. The necessary input data include:

1. The number and thickness of the soil layers.
2. The concentration of salt in the irrigation water.
3. The length of the season and the interval between irrigations.
4. The time between initial soil sampling and the first irrigation.
5. The moisture content and concentration of salt in each layer at initial sampling.
6. For each layer: the fraction of total ET, the upper and lower limits of field moisture, and the maximum allowable concentration of salt in the soil solution.

7. The daily ET for the irrigation season.

8. The leaching factor function for the particular soil.

The evaluation version of the simplified model predicts the water and salt status of the soil profile irrigated according to a given schedule which specifies the depth, timing, and water quality of each irrigation. This version did not predict the field measurements with any accuracy. Ignoring upward flow seriously limits the usefulness of the model in many cases. The uncertainty with which the leaching factor function can be determined for a given soil further limits the model's utility.

From a study using the simplified model for irrigation management, it was found that use of seasonal average quality of irrigation water may not be satisfactory. Whenever the quality fluctuates significantly, it is probably necessary to know the actual quality for each irrigation to reasonably predict salt movement. Studies also showed that season totals of leaching water and salt leaving the soil profile are nearly constant for a rather wide range of irrigation frequencies. However, timing of salt releases was affected by irrigation frequency, with the less frequent irrigations tending to release salt earlier in the season. This would be expected because larger amounts of water tend to move the salts lower.

## Detailed Model

### Water Model

A mathematical model was developed to predict soil water profiles, evaporation, transpiration, drainage, and root potential at the surface in a cropped field as functions of time. The model is for one dimensional unsteady state flow conditions, and can be applied to irrigated and non-irrigated crops.

The model consists of a second-order nonlinear partial differential equation of a parabolic type with a plant extraction term:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} [K(\theta) \frac{\partial H}{\partial z}] + A(z)$$

where A(z) is the root extraction term which depends on root density function, hydraulic conductivity of the soil, plant water potential and soil water potential difference. The solution for the above equation was obtained by a numerical method using a digital computer. The basic input data needed for the solution of the model are:

1. Soil properties: water potential and hydraulic conductivity vs water content curves covering the range of water content to be encountered in the problem; initial water content and salt profiles.
2. Plant properties: root distribution (effective moisture extraction) and the minimum and maximum values allowed for the root water potential.
3. Boundary and climatic properties: precipitation, potential evapotranspiration, potential transpiration, and evaporation as functions of time; presence or absence of water table or layer restricting water flow at the lower boundary.

Soil, plant, and climatic parameters were determined in the field. The total study included two years of field experiments. The crops were oats seeded to alfalfa in 1970 and alfalfa in 1971. Two lysimeters were used to measure actual ET. Neutron and gamma probes were used to measure soil water content profiles. Climatic data were collected from a weather station installed in the field.

The cumulative computed ET was 4.9 cm which was 0.4 cm less than the actual (measured) ET during the nine-day interval in 1970. The use of published crop coefficients together with Penman's equation gave estimates of evapotranspiration that were considerably in error in 1971. Right after cutting the alfalfa, estimated evapotranspiration was too high while later on it was too low. The overall seasonal average of estimated and measured ET was quite close. Since daily estimates were needed to check other parts of the model, the actual measured values of ET were used as the boundary conditions for this purpose. The computed soil water content vs depth profiles agreed very well with measured soil water content vs depth profiles for both crops in 1970 and 1971.

Computed cumulative upward water flow from the water table was 2.2 cm which was 0.10 cm greater than measured in the nine-day period in 1970. However, for 116 days in 1971 the computed cumulative upward flow from the water table was 4.8 cm as compared to 1.6 cm measured upward flow for the whole season.

## Salt Model

A model was developed to describe the simultaneous flow of water and salts in soils under varying initial and boundary conditions. Water and thus the salt movement due to plant root extraction was also considered. To predict the distribution of adsorbed ionic species, corrections were made in their concentrations due to sink or source terms. Specific chemical processes contributing to the sink or source term in the model are:

1. Dissolution or precipitation of gypsum and lime.
2. Formation of undissociated Ca and Mg sulfate.
3. Exchange between cations in solution and the soil matrix.

The principles of solubility product and equilibrium exchange were used. The solutes considered were $Ca^{++}$, $Mg^{++}$, $Na^{+}$, and $Cl^{-}$. The model was tested under field and laboratory conditions. Three cases with different initial and boundary conditions were studied in the laboratory. In the field, the experiment was conducted with alfalfa as the major crop.

Two wetting and drying cycles were monitored in the field. Measurements of water content and salt concentrations were made three times in the experiment. Experimental measurements were then compared with the predicted values. There was a close correspondence between the measured and predicted water content in all experiments. However, predicted total salt concentrations agreed fairly well with the measured values only in the field and one of the column experiments. Chloride ions followed the same distribution pattern as that of total salts in the above experiments. Predicted calcium concentration was higher than the measured values while the opposite was true for predicted magnesium and sodium concentration. It is postulated that these differences result because of: (1) insufficient description of the exchange and activity coefficients at high salt concentrations, and (2) other complex ion formation not included in the model at the present time.

In two laboratory experiments there was poor agreement between the predicted and measured total salt concentration. The lack of agreement seemed to result from the assumptions involved in the present model or some reasons unknown at the present time. Since the salts were applied to the soil surface in the powder form, they were assumed to be soluble at the initial water content. It was concluded that this assumption is one of the reasons for the apparent differences in the predicted and measured values. The investigation regarding the applicability of the model suggests that more tests are needed. It does appear to yield approximately correct values for total salt but individual species are not as accurately described.

## SECTION IX

## ACKNOWLEDGMENTS

Many individuals assisted, encouraged, and supported various phases of work leading to this report. The authors would particularly like to acknowledge the help of Dr. H. B. Peterson, USU,who directed the research grant in its first year.

An advisory committee offered valuable help from time-to-time. This committee consisted of USU faculty members N. B. Jones, Dr. R. L. Smith, Dr. H. B. Peterson, Dr. E. J. Middlebrooks, and EPA personnel M. B. Rainey, Richard Sotiros, Jim Vincent, Russel Freeman, and Dr. J. P. Law, Jr.

The research work was begun on July 1, 1968, under grant #WP-01492-01(N) 1. The work continued from October 1, 1969, until March 31, 1972, under grant #13030 FDJ. Mr. Richard Sotiros, EPA, Denver, served as Project Office from the beginning of the research until June 30, 1971. From July 1, 1971, Dr. James P. Law, Jr., EPA, Ada, was Project Officer.

This report covers two of four subprojects of the research grant. The other two subprojects are covered in separate reports: "Cation Transport in Soils and Factors Affecting Soil Carbonate Solubility" by J. J. Jurinak, Sung-Ho Lai, and J. J. Hassett; and "Herbicide Contamination of Surface Runoff Waters" by J. O. Evans and D. R. Duseja. The authors express special appreciation to M. J. Mickelson and R. B. Backus who served as farm managers in Vernal at different times and supervised the farming operations and field data collection. Appreciation is also expressed to the several graduate students whose theses and dissertations are listed in Section XI.

Preceding page blank

# SECTION X

# REFERENCES

Alfaro, J. F. 1965. A laboratory study of the effect of water application rate on leaching efficiency. Unpublished M.S. Thesis. Utah State University Library, Logan, Utah. 59 p.

Andrade, R. B. 1971. The influence of bulk density on the hydraulic conductivity and water content-matric suction relations of two soils. Unpublished M. S. Thesis. Utah State University Library, Logan, Utah. 49 p.

Biggar, J. W., and D. R. Nielsen. 1963. Miscible displacement, V. Exchange processes. Soil Sci. Soc. Amer. Proc. 27:623-627.

Biggar, J. W., and D. R. Nielsen. 1967. Miscible displacement and leaching phenomenon, p. 254-274. In Irrigation of Agricultural Lands, Amer. Soc. Agron., Madison, Wisconsin. 1180 p.

Bower, C. A., W. R. Gardner, and J. O. Goertzen. 1957. Dynamics of cation exchange in soil columns. Soil Sci. Soc. Amer. Proc. 21: 20-24.

Bresler, E. 1967. A model for tracing salt distribution in the soil profile. Soil Sci. 104:227-233.

Bresler, E., and R. J. Hanks. 1969. Numerical method of estimating simultaneous flow of water and salts in unsaturated soils. Soil Sci. Soc. Amer. Proc. 33:827-832.

Cowan, I. R. 1965. Transport of water in soil-plant-atmosphere system. Journal of Applied Ecology 2:221-229.

Danielson, R. E. 1967. Root systems in relation to irrigation. p. 390-413. In Irrigation of Agricultural Lands. Amer. Soc. Agron., Madison, Wisconsin. 1180 p.

Davidson, J. M., J. W. Biggar, and D. R. Nielsen. 1963. Gamma-radiation attenuation for measuring bulk density and transient water flow in porous media. Journal of Geophysical Research 68:4777-4783.

Preceding page blank

DeVault, D. 1943. The theory of chromatography. J. Amer. Chem. Soc. 65:532-540.

Dumm, L. D. 1968. Subsurface drainage by transient-flow theory. J. Irrigation and Drainage Division, Proc. Amer. Soc. Civil Engr. 94:505-519.

Dutt, G. R. 1963. Development of a computer program for calculating the ionic composition of percolating waters. Dept. Irrigation, Univ. of Calif. Davis. Contribution No. 50. 35 p.

Dutt, G. R. 1964. Effect of small amounts of gypsum in soils on the solutes in effluents. Soil Sci. Soc. Amer. Proc. 28:754-757.

Dutt, G. R., T. C. Tucker, M. J. Shaffer, and W. J. Moore. 1971. Predicting nitrate content of agricultural drain water. Dept. of Agriculture, Chemistry and Soils. Univ. of Arizona, Tucson. 101 p.

Dyer, K. L. 1965. Interpretation of chloride and nitrate ion distribution pattern in adjacent irrigated and non-irrigated Panoche soils. Soil Sci. Soc. Amer. Proc. 29:170-176.

Freeze, R. A. 1969. The mechanism of natural groundwater recharge and discharge. I. One dimensional vertical, unsteady, unsaturated flow above a recharging or discharging groundwater flow system. Water Resource Res., 5:153-171.

Frissel, M. J., and P. Poelstra. 1964. A theoretical approach to the movement of strontium through soils. Soil Sci. 98:274-277.

Frissel, M. J., and P. Poelstra. 1967. Chromatographic transport through soils. I. Theoretical evaluations. Plant and Soils 26:285-302.

Gardner, W. R. 1960. Dynamic aspects of water availability to plants. Soil Sci. 89:63-73.

Gardner, W. R. 1964. Relation of root distribution to water uptake and availability. Agronomy Journal 56:35-41.

Gardner, W. R., and R. H. Brooks. 1957. A descriptive theory of leaching. Soil Sci. 83:295-304.

Gardner, W. R., and C. F. Ehlig. 1962. The influence of soil water on transpiration by plants. Journal of Geophysical Research 68:5719-5724.

Gardner, W.R., and D. Kirkham. 1952. Determination of soil moisture by neutron scattering. Soil Sci. 73:391-401.

Glueckauf, E. 1949. Theory of chromatography. PVI. J. Chem. Soc. 3280-3285.

Gupta, S.C. 1972. Model for predicting simultaneous distribution of salt and water in soil. Unpublished PhD Dissertation, Utah State University Library, Logan, Utah. 112 p.

Hanks, R.J., and S.B. Bowers. 1962. Numerical solution of moisture flow equation for infiltration into layered soils. Soil Sci. Soc. Amer. Proc. 26:530-534.

Hanks, R.J., A. Klute, and E. Bresler. 1969. A numeric method for estimating infiltration, redistribution, drainage, and evaporation of water from soil. Water Resources Res. 5:1064-1069.

Hanks, R.J., and R.W. Shawcroft. 1965. An economical lysimeter for evapotranspiration studies. Note in Agronomy Journal 57:634-637.

Helfferich, F. 1962. Ion exchange. McGraw-Hill Book Company, Inc. 624 p.

Hiester, N.K., and T. Vermeulen. 1952. Saturation performance of ion-exchange and absorption columns. Chem. Engr. Prog. 48:505-516.

Hillel, D. 1971. Soil and Water: Physical Principles and Processes. pp. 201-220. Academic Press, Inc., New York.

Jamil, Abdul. 1971. Comparison of field methods for measuring hydraulic conductivity. Unpublished M.S. Thesis. Utah State University Library, Logan, Utah. 104 p.

Jenab, S.A. 1967. Development of a drainage function for the transient case and a two dimensional groundwater mound study to evaluate aquifer parameters. Unpublished PhD Dissertation. Utah State University Library, Logan, Utah

Jensen, M.E. 1966. Empirical methods of estimating or predicting evapotranspiration using radiation. Proc. ET and Its Role in Water Resources Management, Amer. Soc. Agric. Engr., Chicago 49-53.

Kunz, K. S. 1957. Numerical Analysis. pp. 4-6. McGraw-Hill, New York. 381 p.

Lai, S. 1970. Cation exchange and transport in soil columns undergoing miscible displacement. Unpublished PhD Dissertation. Utah State University Library, Logan, Utah. 128 p.

Lapidus, L., and N. R. Amundson. 1952. Mathematics of adsorption in beds. VI. The effect of longitudinal diffusion in ion exchange and chromatographic columns. J. Phy. Chem. 56:984-988.

Martin, A. J. P., and R. L. M. Synge. 1941. A theory of chromatography. Biochem. J. 35:1358-1364.

McGuinnes, J. L., R. F. Driebelbus, and L. L. Harold. 1961. Soil moisture measurement with the neutron method supplement weighing lysimeters. Soil Sci. Soc. Amer. Proc. 25:239-245.

Molz, F. J. 1971. Interaction of water uptake and root distribution. Agronomy Journal 63:608-610.

Molz, F. J., and I. Remson. 1970. Extraction-term models of soil moisture use by transpiring plants. Water Resources Res. 6:1346-1356.

Molz, F. J., and I. Remson. 1971. Application of an extraction-term model to the study of the moisture flow to plant roots. Agronomy Journal 63:72-77.

Molz, F. J., I. Remson, A. A. Fungaroli, and R. L. Drake. 1968. Soil moisture availability for transpiration. Water Resources Res. 4:1161-1169.

Mortier, P., and M. Deboodt. 1956. Determination of soil moisture by neutron scattering. Netherlands Journal of Agriculture Science 4:111-118.

Nielsen, D. R., and J. W. Biggar. 1962. Miscible displacement: III Theoretical considerations. Soil Sci. Soc. Amer. Proc. 26:216-221.

Nimah, M. N. 1968. The influence of irrigation intervals on water use efficiency measured by the neutron scattering method. Unpublished M. S. Thesis, American University of Beirut, Beirut, Lebanon.

Nimah, M. N. 1972. Model for estimating soil water flow, water content, evapotranspiration, and root extraction. Unpublished PhD Dissertation. Utah State University Library, Logan, Utah. 131 p.

Ogata, G. L., L. A. Richards, and W. R. Gardner. 1960. Transpiration of alfalfa determined from soil water content changes. Soil Sci. 89:179-182.

Olsen, S. R., and F. S. Watanabe. 1959. Solubility of calcium carbonate in calcareous soils. Soil Sci. 88:123-129.

Penman, H. L. 1963. Vegetation and hydrology. Technical Communication No. 53, Commonwealth Bureau of Soils, Harpenden, England. 125 pp.

Philip, J. R. 1957. The physical principles of soil water movement during the irrigation cycle. Proceedings International Congress of Irrigation Drainage, 3rd 8:125-154.

Philip, J. R. 1966. Plant water relations: Some physical aspects. Annual Review of Plant Physiology 17:245-268.

Poulovassilis, A. 1969. The effect of hysteresis of pore water on the hydraulic conductivity. J. Soil Sci. 20:52-56.

Rasheed. H. R. 1970. Irrigation management to control the quality of return flow. Unpublished PhD Dissertation. Utah State University Library, Logan, Utah.

Rible, J. M., and L. E. Davis. 1955. Ion exchange in soil columns. Soil Sci. 79:41-47.

Richards, L. A. 1931. Capillary conduction of liquids in porous medium. Physics 1, 318-333.

Richards, L. A. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agriculture Handbook, No. 60. 160 p.

Robinson, R. A., and R. H. Stokes. 1955. Electrolyte solutions. Academic Press Inc. New York. 512 p.

Rubin, J. 1966. Theory of rainfall uptake by soils initially drier than their field capacity and its applications. Water Resources Res. 2: 739-749.

Slatyer, R. O. 1960. Absorption of water by plants. Botanical Review 26:331-392.

Tanji, K. K., and L. D. Doneen. 1966. Predictions on the solubility of gypsum in aqueous solutions. Water Resources Res. 2:543-548.

Thomas, H. C. 1944. Heterogeneous ion exchange in a flowing system. J. Amer. Chem. Soc. 66:1664-1666.

Thornthwaite, C. W., J. R. Mather, and J. K. Nakamura. 1960. Movement of radioactive strontium in soils. Sci. 131:1015-1019.

Topp, C. G., and E. E. Miller. 1966. Hysteresis moisture characteristics and hydraulic conductivities for glass bead media. Soil Sci. Soc. Amer. Proc. 30:156-162.

United States Environmental Protection Agency. 1971. The mineral quality problem in the Colorado River Basin.

van Bavel, C. H. M., G. B. Stirk, and K. J. Brust. 1968. Hydraulic properties of a clay loam soil and the field measurement of water uptake by roots. I. Interpretation of water content and pressure profiles. Soil Sci. Soc. Amer. Proc. 32:310-317.

van der Molen, W. H. 1956. Desalinization of saline soils as a column process. Soil Sci. 8:19-27.

Whistler, F. D., A. Klute, and R. J. Millington. 1968. Analysis of steady state evapotranspiration from soil columns. Soil Sci. Soc. Amer. Proc. 32:167-174.

Titavunno, P. 1971. Quality of leachate from Vernal project soil as affected by certain conditions in the soil and applied water. Unpublished M. S. Thesis. Utah State University Library, Logan, Utah. 132 p.

# SECTION XI

# PUBLICATIONS RESULTING FROM PROJECT

## Theses and Dissertations

Backus, R. B. 1973. Field evaluation of a computer model for management of irrigation return flow quality. M. S. Thesis. Utah State University.

Campbell, M. D. 1969. Salinity and water potential sensor for evaluation of soil water quality. M. S. Thesis. Utah State University (Partial support from this project).

Gupta, S. C. 1972. Model for predicting simultaneous distribution of salt and water in soils. PhD Dissertation. Utah State University.

Jamil, Abdul. 1971. Comparison of field methods for measuring hydraulic conductivity. M. S. Thesis. Utah State University (Partial support from this project).

Khalil-Ur-Rehman, M. 1971. Field evaluation of various transient drainage equations. M. S. Thesis. Utah State University. (Partial support from this project).

Nimah, M. N. 1972. Model for estimating soil water flow, water content, evapotranspiration and root extraction. PhD Dissertation. Utah State University.

Olson, B. R., Jr. 1971. Evaluation of fluorescent dyes as possible tracers for irrigation return flow measurement. M. S. Thesis. Utah State University (Partial support from this project).

Rasheed, H. R. 1970. Irrigation management to control the quality of return flow. PhD Dissertation. Utah State University.

Titavunno, P. 1971. Quality of leachate from Vernal project soil as affected by certain conditions in the soil and applied water. M. S. Thesis. Utah State University.

## Papers and Publications

Bresler, E., and R. J. Hanks. 1969. Numerical method for estimating simultaneous flow of water and salt in unsaturated soils. Soil Sci. Soc. Amer. Proc. 33:827-833 (Partial support from this project).

Gupta, S. C., and R. J. Hanks. 1972. Influence of water content on electrical conductivity of the soil. Soil Sci. Soc. Amer. Proc. 36: 855-857.

Keller, J., and H. R. Rasheed. 1969. Controlled leaching with unsaturated flow. ASCE, Irrigation and Drainage Division Specialty Conference, "Water in 2020." Austin, Texas, November 5 - 7.

King, L. G., and R. B. Backus. 1972. Drainage water quality as affected by irrigation scheduling. ASCE, Irrigation and Drainage Division Specialty Conference, "The Age of Changing Priorities for Land & Water." Spokane, Washington, September 27 - 28.

King, L. G., R. J. Hanks, M. N. Nimah, S. C. Gupta, and R. B. Backus. 1972. Modeling subsurface return flows in Ashley Valley. Proc. National Conference on Managing Irrigated Agriculture to Improve Water Quality. May 16 - 18, Grand Junction, Colorado. pp. 241-256.

King, L. G., H. R. Rasheed, and J. Keller. 1971. Irrigation scheduling and drainage water quality. Presented at ASCE National Water Resources Engineering Meeting. Phoenix, Arizona, January 11 - 15.

Nimah, M. N., and R. J. Hanks. 1972. Model for estimating soil water, plant and atmospheric interrelations I. Description and sensitivity. Submitted to Soil Sci. Soc. Amer. Proc.

Nimah, M. N., and R. J. Hanks. 1972. Model for estimating soil water, plant and atmospheric interrelations. II. Field test. Submitted to Soil Sci. Soc. Amer. Proc.

Rasheed, H. R., L. G. King, and J. Keller. 1970. Irrigation scheduling based on water and salt budgets. ASAE, Annual Meeting Rocky Mountain Region, Fort Collins, Colorado, April 10 - 11.

Rasheed, H. R., L. G. King, and J. Keller. 1970. Sprinkler irrigation scheduling based on water and salt budgets. Winter Meeting ASAE, Chicago, December 8 - 11, Paper No. 70-736.

# SECTION XII

# APPENDICES

Page

A. Simplified Model
  FORTRAN Listing of Prediction Version 194
  Example 1 - Long Output Prediction Version 202
  Example 2 - Short Output Prediction Version 204
  FORTRAN Listing of Evaluation Version 206
  Example 3 - Sample Output Evaluation Version 210

B. Detailed Model
  FORTRAN Listing of Water Model 215
  FORTRAN Listing Combined Water and Salt Models 223

C. Data and Results
  Tables 34 through 60 239
  Figures 56 through 81 283

# APPENDIX A

## SIMPLIFIED MODEL

### FORTRAN Listing of Prediction Version

```
C     PROGRAM (A) SIMULATES THE [illegible] AND STORAGE OF SALTS IN
C     THE SOIL AND [illegible] THE AMOUNT OF SALT LEAVING THE [illegible]
C     FOR EACH IRRIGATION AND THE ENTIRE SEASON FOR A [illegible]
C     UTAH STATE UNIVERSITY
C     PROJECT [illegible]
C     DEFINITIONS
C      C    IS THE CONCENTRATION OF IRRIGATION WATER  MMHO/CM
C      CA   IS THE AVERAGE INITIAL CONCENTRATION OF THE SOIL SOLUTION  MMHO/CM
C      CE   IS THE CONCENTRATION OF WATER ENTERING A LAYER  MMHO/CM
C      CF   IS THE FINAL CONCENTRATION OF SOIL SOLUTION  MMHO/CM,JUST BEFORE
C           THE NEXT IRRIGATION
C     CFC   CONCENTRATION AT FIELD CAPACITY
C      CL   IS THE CONCENTRATION OF WATER LEAVING A LAYER  MMHO/CM
C      CT   IS THE  CRITICAL CONCENTRATION OF SOIL SOLUTION  MMHO/CM
C   CTTOL   IS THE ITERATION LIMIT
C            (C IS WITHIN + OR - CTTOL FROM CT WHEN ITERATION CEASES)
C      DA   IS THE DEPTH APPLIED/IRRIGATION
C      DE   IS THE DEPTH OF WATER ENTERING A LAYER
C      DL   IS THE DEPTH OF WATER LEAVING A LAYER
C      DT   IS THE THICKNESS OF EACH LAYER FT.
C      ET   IS THE EVAPOTRANSPIRATION INCHES
C      I    DESIGNATES A PARTICULAR LAYER
C  IPRINT   CONTROLS THE TYPE OF PRINT-OUT
C           IPRINT = 0 (OR LEFT BLANK) GIVES LONG PRINT-OUT
C           IPRINT = 1 GIVES SHORT PRINT-OUT
C      J    DESIGNATES A PARTICULAR IRRIGATION
C      KF   IS THE FIRST DAY OF A GIVEN IRRIGATION INTERVAL
C      KK   DESIGNATES A PARTICULAR DAY OF THE SEASON
C      KM   THE FIXED FREQUENCY IN DAYS (IRRIGATION INTERVAL)
C     KM1   IS THE NUMBER OF DAYS FROM INITIAL SAMPLING TO FIRST IRRIGATIO
C      L    IS THE LENGTH OF GROWING SEASON IN DAYS STARTING AT INITIAL SAMPLING
C      N    IS THE NUMBER OF LAYERS IN THE ROOT ZONE
C  NCASES   IS THE NUMBER OF PROBLEMS TO BE COMPUTED FOR THE COMPUTER RUN
C      QA   IS THE INITIAL MOISTURE CONTENT  VOLUMETRIC INITIAL
C      QF   IS THE FINAL MOISTURE CONTENT, JUST BEFORE THE NEXT IRRIGATION
C     QFC   IS THE MOISTURE CONTENT AT FIELD CAPACITY VOLUMETRIC
C      QT   IS THE CRITICAL MOISTURE CONTENT  VOLUMETRIC
C     RK    IS THE PERCENT OF THE ROOTS IN THE PARTICULAR LAYER
C     WTDA  IS THE AMOUNT OF SALT IN A GIVEN LAYER
      DIMENSION C(20),QA(20),QFC(20),DT(20),CT(20),RK(20),WTDA(20),CF(2
     10),CE(20),DE(20),CL(20),QF(20),CE(20),CFC(20),ET(150),[illegible]
     220),ET(150),WTDA(20,200),TSA(20),DF(20,20[illegible]
     3(200),CHL(20),DL(200),DEPTH(200),QA(20),CA(20)
      READ(5,2)NCASES
    2 FORMAT(I5)
      NCASE=0
    1 READ(5,100)IPRINT,N,L,KM,KM1,(X,C,CTTOL
  100 FORMAT(5I3,7F5.0)
      NCASE=NCASE+1
      READ(5,101)(QA(I),I=1,N)
  101 FORMAT(16F5.0)
      READ(5,101)(CA(I),I=1,N)
      READ(5,101)(RK(I),I=1,N)
      READ(5,101)(QFC(I),I=1,N)
      READ(5,101)(QT(I),I=1,N)
      READ(5,101)(DT(I),I=1,N)
    3 READ(5,102)(ET(KK),KK=1,L)
  102 FORMAT(20F4.2)
      DO 203 I=1,N
      CRA(I)=CA(I)
  203 CRA(I)=CRA(I)
      TET=0.0
      DO 51 I=1,L
   51 TET=TET+ET(I)
      RUM=0.0
      CHI=0.
      IF(KM1.NE.0) GO TO 201
      DO 200 I=1,N
```

Reproduced from best available copy.

```
      QB1(I)=0.0
  200 CB1(I)=0.0
  201 J=1
      JMAX=(L+KM-1-KM1)/KM
      JJMAX=JMAX+1
      DO 4 M=1,JJMAX
    4 FTT(M)=0.0
      KF=1+KM1
      KK=KM+KM1
      SAM=0.0
      DD=0.0
      TD=0.0
      DO 14 I=1,N
      D=(QFC(I)-QB(I))*DX*12.0
   14 DD=DD+D
      SAM=DD
      IF(KM1.EQ.0) GO TO 23
      DO 5 I=1,KM1
    5 FTT(1)=FTT(1)+T(I)
      DD=DD+FTT(1)
      SAM=DD
      DO 733 I=1,N
      QBS=QB(I)
      CBS=CB(I)
      QB(I)=QB(I)-(PW(I)*FTT(1))/(DX*12.0)
      CB(I)=QBS*CBS/QB(I)
      QB1(I)=QB(I)
  733 CB1(I)=CB(I)
   23 TSPA=0.0
      DO 13 I=1,N
      WTPA(I)=QB(I)*DX*0.87*CB(I)
   13 TSPA=TSPA+WTPA(I)
  595 IF(J.LT.JMAX) GO TO 217
      KK=L
  217 DO 16 I=KF,KK
   16 FTT(J+1)=FTT(J+1)+T(I)
      IF(J.EQ.1) GO TO 725
      DD=FTT(J)
  725 CF(1)=C
   22 QF(1)=DD
      DO 15 I=1,N
      QFC=QFC(I)*12.*DX
      QBX=QB(I)*DX*12.
      DL(I)=QF(I)-(QFC-QBX)
      IF(DL(I).LT.0.0) GO TO 62
      FR=DL(I)/QFC
      QBX=QB(I)
      CL(I)=CF(I)*(FR*(CB(I)*CF(I)+D*(I))/DL(I))
      CFC(I)=(QBX*CB(I)*CF(I)-DL(I)*CL(I))/QFC
      GO TO 66
   62 DL(I)=0.
      CL(I)=0.
      CFC(I)=(QBX*CB(I)+QF(I)*CF(I))/QFC
   66 CF(I+1)=CL(I)
   15 QF(I+1)=DL(I)
      IF(DD.GT.20.0) GO TO 777
      IF((FTT(J)+0.00)).GT.DD) GO TO 67
      WLPA(J)=DL(N)*CL(N)*0.9/12.1
      GO TO 68
   67 WLPA(J)=0.0
   68 DO 17 I=1,N
      QF(I)=QFC(I)-(PW(I)*FTT(J+1))/(DX*12.0)
      CF(I)=QFC(I)*CF(I)/QF(I)
      IF(QF(I).LT.QT(I)) GO TO 19
      DIF=CF(I)-CT(I)
      IC=I
      IF(DIF.GT.CTTOL) GO TO 18
   17 CONTINUE
      GO TO 195
   19 DIFA DIF
      A=DD
      DD=DD*.5
  182 QF(1)=DD
      DO 185 I=1,IC
      QFC=QFC(I)*12.*DX
      QBX=QB(I)*12.*DX
      DL(I)=QF(I)-(QFC-QBX)
      IF(DL(I).LT.0.) GO TO 184
      FR=DL(I)/QFC
      QBX=QB(I)
      CL(I)=QF(I)*(FR*(CB(I)*CF(I)*CF(I)+EX*( [illegible] (I))/DL(I)
      CFC(I)=(QF(I)*CF(I)+CB(I)*C(I)*( [illegible] (I)-CL(I)*CL(I))/QFC
      GO TO 185
  184 DL(I)=0.
```

Reproduced from
best available copy.

```
000            CL(I)=0.
000            CFC(I)=(DEX*CB(I)+DF(I)*CF(I))/DFC
000       185 CF(I+1)=CL(I)
000       183 DF(I+1)=DL(I)
000            QF(IC)=QFC(IC)-(RK(IC)*FT(J+1))/(DX*12.)
000            CF(IC)=QFC(IC)*CFC(IC)/QF(IC)
000            DIF=CF(IC)-CT(IC)
000            IF(DIF) 1195,22,192
000      1195 DIFB=DIF
000            B=DD
000       193 DD=A+(DIFA*(B-A))/(DIFA-DIFB)
000       196 DF(1)=DD
000            DO 187 I=1,IC
000            DFC=QFC(I)*12.*DX
000            DFX=QB(I)*12.*DX
000            DL(I)=DF(I)-(DFC-DFX)
000            IF(DL(I).LE.0.) GO TO 188
000            FR=DL(I)/DFC
000            QFX=QB(I)
000            CL(I)=PF(QFX,FR)*(DF(I)*CF(I)+DFX*CB(I))/DL(I)
000            CFC(I)=(DEX*CB(I)+DF(I)*CE(I)-DL(I)*CL(I))/DFC
000            GO TO 189
000       188 DL(I)=0.
000            CL(I)=0.
000            CFC(I)=(DEX*CB(I)+DF(I)*CF(I))/DFC
000       189 CE(I+1)=CL(I)
000       187 DF(I+1)=DL(I)
000            QF(IC)=QFC(IC)-(RK(IC)*FT(J+1))/(DX*12.)
000            CF(IC)=QFC(IC)*CFC(IC)/QF(IC)
000            DIF=CF(IC)-CT(IC)
000            IF(ABS(DIF).LT.CTTOL) GO TO 22
000            IF(DIF) 191,22,192
000       191 DIFB1=DIF
000            B1=DD
000            DD=B1+(DIFB1*(B-B1))/(DIFB1-DIFB)
000            DIFB=DIF
000            B=B1
000            IF(DD.LE.A) GO TO 193
000            A=DD
000            DF(1)=DD
000            DO 196 I=1,IC
000            DFC=QFC(I)*12.*DX
000            DFX=QB(I)*12.*DX
000            DL(I)=DF(I)-(DFC-DFX)
000            IF(DL(I).LE.0.) GO TO 197
000            FR=DL(I)/DFC
000            QFX=QB(I)
000            CL(I)=PF(QFX,FR)*(DF(I)*CL(I)+DFX*CB(I))/DL(I)
000            CFC(I)=(DEX*CB(I)+DF(I)*CE(I)-DL(I)*CL(I))/DFC
000            GO TO 198
000       197 DL(I)=0.
000            CL(I)=0.
000            CFC(I)=(DEX*CB(I)+DF(I)*CF(I))/DFC
000       198 CF(I+1)=CL(I)
000       196 DF(I+1)=DL(I)
000            QF(IC)=QFC(IC)-(RK(IC)*FT(J+1))/(DX*12.)
000            CF(IC)=QFC(IC)*CFC(IC)/QF(IC)
000            DIFA=CF(IC)-CT(IC)
000            IF(DIFA.LT.CTTOL) GO TO 22
000            GO TO 193
000       192 DIFA1=DIF
000            A1=DD
000            DD=A+(DIFA*(A1-A))/(DIFA-DIFA1)
000            DIFA=DIF
000            A=A1
000            IF(DD.GE.B) GO TO 193
000            B=DD
000            DF(1)=DD
000            DO 1196 I=1,IC
000            DFC=QFC(I)*12.*DX
000            DFX=QB(I)*12.*DX
000            DL(I)=DF(I)-(DFC-DFX)
000            IF(DL(I).LE.0.) GO TO 1197
000            FR=DL(I)/DFC
000            QFX=QB(I)
000            CL(I)=PF(QFX,FR)*(DF(I)*CF(I)+DFX*CB(I))/DL(I)
000            CFC(I)=(DEX*CB(I)+DF(I)*CE(I)-DL(I)*CL(I))/DFC
000            GO TO 1198
000      1197 DL(I)=0.
000            CL(I)=0.
000            CFC(I)=(DEX*CB(I)+DF(I)*CE(I))/DFC
000      1198 CF(I+1)=CL(I)
000      1196 DF(I+1)=DL(I)
000            QF(IC)=QFC(IC)-(RK(IC)*FT(J+1))/(DX*12.)
```

```
      CF(IC)=OFC(IC)*CFC(IC)/OF(IC)
      DIFR=CF(IC)-CT(IC)
      IF(ABS(DIFR).LT.CTTOL) GO TO 22
      GO TO 193
  195 DO 24 I=1,N
      OB(I)=OF(I)
   24 CB(I)=CF(I)
      TSPA1(J)=0.0
      DO 590 I=1,N
      WTPA1(I,J)=OF(I)*DX*.87*CF(I)
  590 TSPA1(J)=TSPA1(J)+WTPA1(I,J)
      DO 591 I=1,N
      OF1(I,J)=OF(I)
  591 CF1(I,J)=CF(I)
      DEPTH(J)=DD
      IF(J.GT.1) GO TO 730
      CHL(1)=DD-SAP
      GO TO 731
  730 CHL(J)=DD-CTT(J)
      CHLT=CHLT+CHL(J)
      RL(J)=CHL(J)*100./DD
      BUM=BUM+WLPA(J)
  731 J=J+1
      KF=KF+KM
      KK=KK+KM
      TD=TD+DD
      RLT=CHLT*100./TD
      IF(J.LE.JMAX) GO TO 595
      CALL PRINT(BUM,C,CBA,CB1,CF1,CHL,CHLT,CT,CTTOL,DEPTH,DX,ET,ETT,JMA
     1X,KM,KM1,L,OBA,OB1,OF1,OFC,QT,RK,RL,RLT,TD,TET,TSPA,TSPA1,WLPA,WTP
     2A,WTPA1,N,IPRINT)
      GO TO 777
   19 WRITE(6,333)
  333 FORMAT(31H THIS FREQUANCY IS NOT POSSIBLE/)
  777 CONTINUE
      IF(NCASE.LT.NCASES) GO TO 1
      STOP
      END
```

```
      FUNCTION PF(QEX,ER)
      DIMENSION A(5,3),B(9)
      DATA((A(I,J),J=1,3),I=1,5)/-.65575,7.0434,-20.536,.45808,-7.1102,
     X22.544,-.044719,1.4081,-11.714,-.019777,-.30143,2.5471,.030781,
     X-2.4902,15.651/
      DO 10 I=1,5
   10 B(I)=A(I,1)+A(I,2)*QEX+A(I,3)*QEX**2
      IF(ER.LT.0.2) GO TO 1
      IF(ER.GE.0.2.AND.ER.LE.3.) GO TO 2
    3 PFLOG=B(1)+B(2)*ALOG(3.)+B(3)*(ALOG(3.))**2+B(4)*(ALOG(3.))**3+B(5
     X)/3.
      PF3=EXP(PFLOG)
      B(9)=B(2)+2.*B(3)*ALOG(3.)+3.*B(4)*(ALOG(3.))**2-B(5)/3.
      B(8)=PF3/3.**B(9)
      PF=B(8)*ER**B(9)
      IF(PF.GT.1.)  PF=1.
      GO TO 4
    1 PFLOG=B(1)+B(2)*ALOG(.2)+B(3)*(ALOG(.2))**2+B(4)*(ALOG(.2))**3+B(5
     X)/.2
      PF2=EXP(PFLOG)
      B(7)=B(2)+2.*B(3)*ALOG(.2)+3.*B(4)*(ALOG(.2))**2-B(5)/.2
      B(6)=PF2/.2**B(7)
      PF=B(6)*ER**B(7)
      GO TO 4
    2 PFLOG=B(1)+B(2)*ALOG(ER)+B(3)*(ALOG(ER))**2+B(4)*(ALOG(ER))**3+B(5
     X)/ER
      PF=EXP(PFLOG)
    4 CONTINUE
      RETURN
      END
      SUBROUTINE PRINT(RUN,C,CBA,CB1,CF1,CHL,CHLT,CT,CTTOL,DEPTH,DX,FT,F
     1TT,JMAX,KM,KM1,L,QBA,QB1,QF1,QFC,QT,RK,PL,PLT,TQ,TET,TSPA,TSPA1,WL
     2PA,WTPA,WTPA1,N,IPRINT)
      DIMENSION CBA(20),CF1(20,20),CHL(20),CT(20),DEPTH(20),FT(150),F
     1TT(150),QBA(20),QF1(20,20),QFC(20),QT(20),RK(20),PL(20),TSPA1(2
     20),WLPA(20),WTPA1(20,20),WTPA(20),QB1(20),CB1(20)
      WRITE(6,500)
  500 FORMAT('1INPUTS',13X,'LAYER     RK       QFC        QT        CT'/53X
     1,'(MMHO/CM)')
      WRITE(6,501)(I,RK(I),QFC(I),QT(I),CT(I),I=1,N)
  501 FORMAT(1H ,20X,I2,3F9.2,F10.2)
      WRITE(6,502)C,DX,L,KM,KM1,CTTOL
  502 FORMAT(' C=',F5.2,4X,'DX=',F6.2,4X,'L=',I3,4X,'KM=',I2,4X,'KM1=',I
     12,4X,'CTTOL=',F5.3//)
      IF(IPRINT.EQ.1) GO TO 2001
      WRITE(6,503)
  503 FORMAT(' INITIAL SOIL CONDITIONS',43X,'DAILY EVAPOTRANSPIRATION'/1
     1X,'LAYER   QB      CB',55X,'(INCHES)'/14X,'(MMHO/CM)',12('   DAY F
     2T'))
  504 FORMAT(I6,F7.2,F8.2,3X,12(I5,F6.2))
      NX=(L-1)/12+1
      DO 505 I=1,N
      WRITE(6,504)I,QBA(I),CBA(I),(KK,FT(KK),KK=I,L,NX)
  505 IF(I.EQ.NX) GO TO 506
      IF(N.EQ.NX) GO TO 507
      II=N+1
      DO 403 M=II,NX
  403 WRITE(6,404)(KK,FT(KK),KK=M,L,NX)
  404 FORMAT(24X,12(I5,F6.2))
      GO TO 507
  506 IF(I.EQ.N) GO TO 507
      I=I+1
      WRITE(6,5004)(II,QBA(II),CBA(II),II=I,N)
 5004 FORMAT(I6,F7.2,F8.2)
  507 WRITE(6,508)
  508 FORMAT('0 ')
      IF(JMAX.GE.4)GO TO 603
      GO TO (510,511,512),JMAX
  510 WRITE(6,513)
  513 FORMAT(' IMMEDIATELY PRIOR TO IRRIG 1      AFTER IRRIG INTERVAL 1'
     1/'0   SOIL  SALT  MOIST   CONC           SALT  MOIST  CONC'/4X,'LAYER
     2 T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM')
      IF(KM1.EQ.0) GO TO 5000
      DO 586 I=1,N
  586 WRITE(6,514)I,WTPA(I),QB1(I),CB1(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
     1J=1,JMAX)
  514 FORMAT(I7,2F7.4,F8.4,1X,4(F10.4,F7.4,F8.4))
      GO TO 5001
 5000 DO 5586 I=1,N
 5586 WRITE(6,514)I,WTPA(I),QBA(I),CBA(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
     1J=1,JMAX)
 5001 WRITE(6,530)TSPA,(TSPA1(J),J=1,JMAX)
  530 FORMAT(' TOTAL',F8.4,7X,4(13X,F7.4))
      WRITE(6,531)FTT(1),(J,DEPTH(J),J=1,JMAX)
  531 FORMAT('0ET PRIOR TO IRRIG 1=',F6.2,' IN',2X,1(4X,'DEPTH IRRIG',I2
     1,1H=,F6.2,' IN'))
      WRITE(6,532)(WLPA(J),J=1,JMAX)
  532 FORMAT(31X,1(3X,'SALT LEAVING=',F6.2,' T/AC'))
      WRITE(6,553)(CHL(J),J=1,JMAX)
  553 FORMAT(31X,1(3X,'LEACHING WATER=',F6.2,' IN'))
      WRITE(6,534)(PL(J),J=1,JMAX)
  534 FORMAT(32X,1(2X,'LEACH REQ=',F5.2,' PERCENT'))
      WRITE(6,535)(J,FTT(J+1),J=1,JMAX)
  535 FORMAT(30X,1(4X,'ET,INTERVAL',I2,1H=,F6.2,' IN'))
      GO TO 585
  511 WRITE(6,515)(J,J=1,2)
  515 FORMAT(' IMMEDIATELY PRIOR TO IRRIG 1   ',2(5X,'AFTER IRRIG INTERVA
     1L',I2)/'0   SOIL  SALT  MOIST   CONC',1X,2(7X,'SALT  MOIST   CONC'
     2)/4X,'LAYER T/AC  CONT   MMHO/CM',1X,2(5X,'T/AC  CONT   MMHO/CM'))
      IF(KM1.EQ.0) GO TO 6000
      DO 686 I=1,N
  686 WRITE(6,514)I,WTPA(I),QB1(I),CB1(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
     1J=1,JMAX)
      GO TO 6001
 6000 DO 6686 I=1,N
 6686 WRITE(6,514)I,WTPA(I),QBA(I),CBA(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
     1J=1,JMAX)
 6001 WRITE(6,530)TSPA,(TSPA1(J),J=1,JMAX)
      WRITE(6,631)FTT(1),(J,DEPTH(J),J=1,JMAX)
  631 FORMAT('0ET PRIOR TO IRRIG 1=',F6.2,' IN',2X,2(4X,'DEPTH IRRIG',I2
     1,1H=,F6.2,' IN'))
      WRITE(6,632)(WLPA(J),J=1,JMAX)
  632 FORMAT(31X,2(3X,'SALT LEAVING=',F6.2,' T/AC'))
      WRITE(6,653)(CHL(J),J=1,JMAX)
 653 FORMAT(31X,2(3X,'LEACHING WATER=',F4.2,' IN'))
     WRITE(6,634)(RL(J),J=1,JMAX)
 634 FORMAT(32X,2(2X,'LEACH REQ=',F5.2,' PERCENT'))
     WRITE(6,635)(J,ETT(J+1),J=1,JMAX)
 635 FORMAT(30X,2(4X,'ET,INTERVAL',I2,1H=,F4.2,' IN'))
     GO TO 585
 512 WRITE(6,516)(J,J=1,3)
 516 FORMAT(' IMMEDIATELY PRIOR TO IRRIG 1  ',3(3X,'AFTER IRRIG INTERVA
    1L',I2)/'0  SOIL  SALT  MOIST  CONC',1X,3(7X,'SALT  MOIST  CONC'
    2)/4X,'LAYER T/AC  CONT  MMHO/CM',1X,3(5X,'T/AC  CONT  MMHO/CM'))
     IF(KM1.EQ.0) GO TO 7000
     DO 786 I=1,N
 786 WRITE(6,514)I,WTPA(I),QB1(I),CB1(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
    1J=1,JMAX)
     GO TO 7001
7000 DO 7786 I=1,N
7786 WRITE(6,514)I,WTPA(I),QBA(I),CBA(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
    1J=1,JMAX)
7001 WRITE(6,530)TSPA,(TSPA1(J),J=1,JMAX)
     WRITE(6,731)ETT(1),(J,DEPTH(J),J=1,JMAX)
 731 FORMAT('DET PRIOR TO IRRIG 1=',F4.2,' IN',2X,3(4X,'DEPTH IRRIG',I2
    1,1H=,F4.2,' IN'))
     WRITE(6,732)(WLPA(J),J=1,JMAX)
 732 FORMAT(31X,3(3X,'SALT LEAVING=',F4.2,' T/AC'))
     WRITE(6,753)(CHL(J),J=1,JMAX)
 753 FORMAT(31X,3(3X,'LEACHING WATER=',F4.2,' IN'))
     WRITE(6,734)(RL(J),J=1,JMAX)
 734 FORMAT(32X,3(2X,'LEACH REQ=',F5.2,' PERCENT'))
     WRITE(6,735)(J,ETT(J+1),J=1,JMAX)
 735 FORMAT(30X,3(4X,'ET,INTERVAL',I2,1H=,F4.2,' IN'))
     GO TO 585
 509 WRITE(6,517)(J,J=1,4)
 517 FORMAT(' IMMEDIATELY PRIOR TO IRRIG 1  ',4(3X,'AFTER IRRIG INTERVA
    1L',I2)/'0  SOIL  SALT  MOIST  CONC',1X,4(7X,'SALT  MOIST  CONC'
    2)/4X,'LAYER T/AC  CONT  MMHO/CM',1X,4(5X,'T/AC  CONT  MMHO/CM'))
     IF(KM1.EQ.0) GO TO 8000
     DO 886 I=1,N
 886 WRITE(6,514)I,WTPA(I),QB1(I),CB1(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
    1J=1,4)
     GO TO 8001
8000 DO 8886 I=1,N
8886 WRITE(6,514)I,WTPA(I),QBA(I),CBA(I),(WTPA1(I,J),QF1(I,J),CF1(I,J),
    1J=1,4)
8001 WRITE(6,530)TSPA,(TSPA1(J),J=1,4)
     WRITE(6,831)ETT(1),(J,DEPTH(J),J=1,4)
 831 FORMAT('DET PRIOR TO IRRIG 1=',F4.2,' IN',2X,4(4X,'DEPTH IRRIG',I2
    1,1H=,F4.2,' IN'))
     WRITE(6,832)(WLPA(J),J=1,4)
 832 FORMAT(31X,4(3X,'SALT LEAVING=',F4.2,' T/AC'))
     WRITE(6,853)(CHL(J),J=1,4)
 853 FORMAT(31X,4(3X,'LEACHING WATER=',F4.2,' IN'))
     WRITE(6,834)(RL(J),J=1,4)
 834 FORMAT(32X,4(2X,'LEACH REQ=',F5.2,' PERCENT'))
     WRITE(6,835)(J,ETT(J+1),J=1,4)
 835 FORMAT(30X,4(4X,'ET,INTERVAL',I2,1H=,F4.2,' IN'))
     IXP=5
     IX=9
     IF(JMAX.GT.4)GO TO 20
     GO TO 585
  20 IF(JMAX.GE.IX)GO TO 90
     JXP=JMAX-IXP+1
     GO TO (101,102,103,104),JXP
1001 IF(IX.EQ.19.OR.IX.EQ.29.OR.IX.EQ.39.OR.IX.EQ.49.OR.IX.EQ.59.OR.IX.
    1EQ.69) GO TO 101
     WRITE(6,911)(J,J=IXP,JMAX)
 911 FORMAT(1H ,1('AFTER IRRIG INTERVAL',I3,4X)/1H0,1('  SALT  MOIST
    1CONC',7X)/1H ,1('  T/AC  CONT   MMHO/CM',5X))
     GO TO 3
 101 WRITE(6,21)(J,J=IXP,JMAX)
  21 FORMAT(1H1,1('AFTER IRRIG INTERVAL',I3,4X)/1H0,1('  SALT  MOIST
    1CONC',7X)/1H ,1('  T/AC  CONT   MMHO/CM',5X))
   3 DO 22 I=1,N
  22 WRITE(6,23)(WTPA1(I,J),QF1(I,J),CF1(I,J),J=IXP,JMAX)
  23 FORMAT(1H F6.4,F7.4,F8.4,4(F12.4,F7.4,F8.4))
     WRITE(6,24)(TSPA1(J),J=IXP,JMAX)
  24 FORMAT(1H ,F6.4,4(20X,F7.4))
     WRITE(6,25)(J,DEPTH(J),J=IXP,JMAX)
  25 FORMAT(1H0,1('DEPTH IRRIG',I3,1H=,F4.2,' IN',5X))
     WRITE(6,26)(WLPA(J),J=IXP,JMAX)
  26 FORMAT(1H ,1('SALT LEAVING=',F4.2,' T/AC',5X))
     WRITE(6,27)(CHL(J),J=IXP,JMAX)
  27 FORMAT(1H ,1('LEACHING WATER=',F4.2,' IN',5X))
     WRITE(6,28)(RL(J),J=IXP,JMAX)
  28 FORMAT(1H ,1('LEACH REQ=',F5.2,' PERCENT',4X))
```

```
000          WRITE(6,29)(J,ETT(J+1),J=IXP,JMAX)
000       29 FORMAT(1H ,1('ET.INTERVAL',I3,1H=,F4.2,' IN',5X))
000          GO TO 585
000     1002 IF(IX.EQ.19.OR.IX.EQ.29.OR.IX.EQ.39.OR.IX.EQ.49.OR.IX.EQ.59.OR.IX.
000         1EQ.69) GO TO 102
000          WRITE(6,910)(J,J=IXP,JMAX)
000      910 FORMAT(1H ,2('AFTER IRRIG INTERVAL',I3,4X)/1H0,2('  SALT  MOIST
000         1CONC',7X)/1H ,2('  T/AC  CONT   MMHO/CM',5X))
000          GO TO 4
000      102 WRITE(6,31)(J,J=IXP,JMAX)
000       31 FORMAT(1H1,2('AFTER IRRIG INTERVAL',I3,4X)/1H0,2('  SALT  MOIST
000         1CONC',7X)/1H ,2('  T/AC  CONT   MMHO/CM',5X))
000        4 DO 32 I=1,N
000       32 WRITE(6,23)(WTPA1(I,J),OF1(I,J),CF1(I,J),J=IXP,JMAX)
000          WRITE(6,24)(TSPA1(J),J=IXP,JMAX)
000          WRITE(6,35)(J,DEPTH(J),J=IXP,JMAX)
000       35 FORMAT(1H0,2('DEPTH IRRIG',I3,1H=,F4.2,' IN',5X))
000          WRITE(6,36)(WLPA(J),J=IXP,JMAX)
000       36 FORMAT(1H ,2('SALT LEAVING=',F4.2,' T/AC',5X))
000          WRITE(6,37)(CHL(J),J=IXP,JMAX)
000       37 FORMAT(1H ,2('LEACHING WATER=',F4.2,' IN',5X))
000          WRITE(6,38)(RL(J),J=IXP,JMAX)
000       38 FORMAT(1H ,2('LEACH REQ=',F5.2,' PERCENT',4X))
000          WRITE(6,39)(J,ETT(J+1),J=IXP,JMAX)
000       39 FORMAT(1H ,2('ET.INTERVAL',I3,1H=,F4.2,' IN',5X))
000          GO TO 585
000     1003 IF(IX.EQ.19.OR.IX.EQ.29.OR.IX.EQ.39.OR.IX.EQ.49.OR.IX.EQ.59.OR.IX.
000         1EQ.69) GO TO 103
000          WRITE(6,909)(J,J=IXP,JMAX)
000      909 FORMAT(1H ,3('AFTER IRRIG INTERVAL',I3,4X)/1H0,3('  SALT  MOIST
000         1CONC',7X)/1H ,3('  T/AC  CONT   MMHO/CM',5X))
000          GO TO 5
000      103 WRITE(6,41)(J,J=IXP,JMAX)
000       41 FORMAT(1H1,3('AFTER IRRIG INTERVAL',I3,4X)/1H0,3('  SALT  MOIST
000         1CONC',7X)/1H ,3('  T/AC  CONT   MMHO/CM',5X))
000        5 DO 42 I=1,N
000       42 WRITE(6,23)(WTPA1(I,J),OF1(I,J),CF1(I,J),J=IXP,JMAX)
000          WRITE(6,24)(TSPA1(J),J=IXP,JMAX)
000          WRITE(6,45)(J,DEPTH(J),J=IXP,JMAX)
000       45 FORMAT(1H0,3('DEPTH IRRIG',I3,1H=,F4.2,' IN',5X))
000          WRITE(6,46)(WLPA(J),J=IXP,JMAX)
000       46 FORMAT(1H ,3('SALT LEAVING=',F4.2,' T/AC',5X))
000          WRITE(6,47)(CHL(J),J=IXP,JMAX)
000       47 FORMAT(1H ,3('LEACHING WATER=',F4.2,' IN',5X))
000          WRITE(6,48)(RL(J),J=IXP,JMAX)
000       48 FORMAT(1H ,3('LEACH REQ=',F5.2,' PERCENT',4X))
000          WRITE(6,49)(J,ETT(J+1),J=IXP,JMAX)
000       49 FORMAT(1H ,3('ET.INTERVAL',I3,1H=,F4.2,' IN',5X))
000          GO TO 585
000     1004 IF(IX.EQ.19.OR.IX.EQ.29.OR.IX.EQ.39.OR.IX.EQ.49.OR.IX.EQ.59.OR.IX.
000         1EQ.69) GO TO 104
000          WRITE(6,908)(J,J=IXP,JMAX)
000      908 FORMAT(1H ,4('AFTER IRRIG INTERVAL',I3,4X)/1H0,4('  SALT  MOIST
000         1CONC',7X)/1H ,4('  T/AC  CONT   MMHO/CM',5X))
000          GO TO 6
000      104 WRITE(6,51)(J,J=IXP,JMAX)
000       51 FORMAT(1H1,4('AFTER IRRIG INTERVAL',I3,4X)/1H ,4('  SALT  MOIST
000         1CONC',7X)/1H ,4('  T/AC  CONT   MMHO/CM',5X))
000        6 DO 52 I=1,N
000       52 WRITE(6,23)(WTPA1(I,J),OF1(I,J),CF1(I,J),J=IXP,JMAX)
000          WRITE(6,24)(TSPA1(J),J=IXP,JMAX)
000          WRITE(6,55)(J,DEPTH(J),J=IXP,JMAX)
000       55 FORMAT(1H0,4('DEPTH IRRIG',I3,1H=,F4.2,' IN',5X))
000          WRITE(6,56)(WLPA(J),J=IXP,JMAX)
000       56 FORMAT(1H ,4('SALT LEAVING=',F4.2,' T/AC',5X))
000          WRITE(6,57)(CHL(J),J=IXP,JMAX)
000       57 FORMAT(1H ,4('LEACHING WATER=',F4.2,' IN',5X))
000          WRITE(6,58)(RL(J),J=IXP,JMAX)
000       58 FORMAT(1H ,4('LEACH REQ=',F5.2,' PERCENT',4X))
000          WRITE(6,59)(J,ETT(J+1),J=IXP,JMAX)
000       59 FORMAT(1H ,4('ET.INTERVAL',I3,1H=,F4.2,' IN',5X))
000          GO TO 585
000      907 IF(IX.EQ.19.OR.IX.EQ.29.OR.IX.EQ.39.OR.IX.EQ.49.OR.IX.EQ.59.OR.IX.
000         1EQ.69) GO TO 90
000          WRITE(6,1)(J,J=IXP,IX)
000        1 FORMAT(1H ,4('AFTER IRRIG INTERVAL',I3,4X),'AFTER IRRIG INTERVAL',
000         1I3/1H0,4('  SALT  MOIST   CONC',7X),'  SALT  MOIST   CONC'/1H ,4('
000         2  T/AC  CONT   MMHO/CM',5X),'  T/AC  CONT   MMHO/CM')
000          GO TO 2
000       90 WRITE(6,61)(J,J=IXP,IX)
000       61 FORMAT(1H1,4('AFTER IRRIG INTERVAL',I3,4X),'AFTER IRRIG INTERVAL',
000         1I3/1H0,4('  SALT  MOIST   CONC',7X),'  SALT  MOIST   CONC'/1H ,4('
000         2  T/AC  CONT   MMHO/CM',5X),'  T/AC  CONT   MMHO/CM')
000        2 DO 62 I=1,N
```

```
000          62 WRITE(6,23)(WTPA1(I,J),QF1(I,J),CF1(I,J),J=IXP,IX)
000             WRITE(6,24)(TSPA1(J),J=IXP,IX)
000             WRITE(6,65)(J,DEPTH(J),J=IXP,IX)
000          65 FORMAT(1H0,4('DEPTH IRRIG',I3,1H=,F4.2,' IN',5X),'DEPTH IRRIG',I3,
000            11H=,F4.2,' IN')
000             WRITE(6,66)(WLPA(J),J=IXP,IX)
000          66 FORMAT(1H ,4('SALT LEAVING=',F4.2,' T/AC',5X),'SALT LEAVING=',F4.2
000            1,' T/AC')
000             WRITE(6,67)(CHL(J),J=IXP,IX)
000          67 FORMAT(1H ,4('LEACHING WATER=',F4.2,' IN',5X),'LEACHING WATER=',F4
000            1.2,' IN')
000             WRITE(6,68)(RL(J),J=IXP,IX)
000          68 FORMAT(1H ,4('LEACH REQ=',F5.2,' PERCENT',4X),'LEACH REQ=',F5.2,'
000            1PERCENT')
000             WRITE(6,69)(J,ETT(J+1),J=IXP,IX)
000          69 FORMAT(1H ,4('ET,INTERVAL',I3,1H=,F4.2,' IN',5X),'ET,INTERVAL',I3,
000            11H=,F4.2,' IN'//)
000             IXP=IX+1
000             IX=IX+5
000             IF(JMAX.GE.IXP) GO TO 40
000             GO TO 585
000          40 IF(JMAX.LT.IX)GO TO 8
000             GO TO 907
000           8 JXP=JMAX-IXP+1
000             GO TO (1001,1002,1003,1004),JXP
000         585 WRITE(6,900)
000         900 FORMAT(' '/)
000             GO TO 2000
000        2001 WRITE(6,2002)
000        2002 FORMAT(' INITIAL SOIL CONDITIONS',2X,'IMMEDIATELY PRIOR TO IRRIG I
000            1'//'   LAYER   GW      CW',11X,'SALT   MOIST   CONT'/' ',19X,'(MMH
000            20/CM)',9X,'(T/AC)  CONT  (MMHO/CM)')
000             IF(KM1.EQ.0) GO TO 3001
000             DO 2003 I=1,N
000        2003 WRITE(6,2004)I,QRA(I),CRA(I),WTPA(I),QR1(I),CR1(I)
000        2004 FORMAT(I7,F7.2,F8.2,8X,3F8.4)
000             GO TO 3004
000        3001 DO 3003 I=1,N
000        3003 WRITE(6,2004)I,QRA(I),CRA(I),WTPA(I),QRA(I),CRA(I)
000        3004 WRITE(6,2005)TSPA,ETT(1)
000        2005 FORMAT(26X,'TOTAL',F7.4,8X,'PRIOR ET=',F5.2///)
000             WRITE(6,2006)
000        2006 FORMAT(19X,'DAILY EVAPOTRANSPIRATION'/27X,'(INCHES)')
000             WRITE(6,2007)
000        2007 FORMAT(' ',7('DAY ET    '))
000             NX=(L-1)/7+1
000             DO 2008 M=1,NX
000        2008 WRITE(6,2009)(KK,ET(KK),KK=M,L,NX)
000        2009 FORMAT(' 'I2,F8.2,6(I5,F8.2))
000             WRITE(6,2020)
000        2020 FORMAT('1  AFTER     SALT       SALT     WATER  LEACHING  LEACHING
000            1ET FOR'/'   IRRIG  EXISTING  LEAVING  APPLIED  WATER      REQ.
000            2INTERVAL'/' INTERVAL  (T/AC)     (T/AC)     (IN)     (IN)     (PERCENT
000            3)   (IN)')
000             WRITE(6,2021)(J,TSPA1(J),WLPA(J),DEPTH(J),CHL(J),RL(J),ETT(J+1),J=
000            11,JMAX)
000        2021 FORMAT(I6,F10.2,F9.2,F10.2,F8.2,F11.2,F9.2)
000             WRITE(6,2022)(TSPA1(JMAX),BUM,TD,CHLT,RLT,TET)
000        2022 FORMAT('  SEASON',F8.2,F9.2,F10.2,F8.2,F11.2,F9.2)
000             GO TO 9000
000        2000 WRITE(6,901)
000         901 FORMAT(' SEASON TOTALS')
000             WRITE(6,902)TD
000         902 FORMAT('0    DEPTH OF IRRIGATION WATER =',F6.2,' INCHES')
000             WRITE(6,903)BUM
000         903 FORMAT(5X,'AMOUNT OF SALT LEAVING THE ROOT ZONE =',F5.2,' TONS PER
000            1 ACRE')
000             WRITE(6,904)CHLT
000         904 FORMAT(5X,'DEPTH OF LEACHING WATER =',F6.2,' INCHES')
000             WRITE(6,905)RLT
000         905 FORMAT(5X,'LEACHING REQUIREMENT =',F6.2,' PERCENT')
000             WRITE(6,906)TET
000         906 FORMAT(5X,'DEPTH OF EVAPOTRANSPIRATION =',F6.2,' INCHES')
000        9000 CONTINUE
000             RETURN
000             END
```

## Example 1 - Long Output Prediction Version

```
INPUTS                LAYER     PK      OFC       GT       CT
                                                         (MMHO/CM)
                        1       .17     .28      .08      5.00
                        2       .12     .28      .08      5.18
                        3       .11     .28      .08      5.36
                        4       .11     .28      .08      5.55
                        5       .10     .28      .08      5.73
                        6       .09     .28      .08      5.91
                        7       .08     .28      .08      6.09
                        8       .07     .28      .08      6.27
                        9       .05     .28      .08      6.45
                       10       .04     .28      .08      6.64
                       11       .03     .28      .08      6.82
                       12       .03     .28      .08      7.00
C= 2.00    DX= .50    L=121     KM=10     KM = 0     CTTOL= .001

INITIAL  SOIL  CONDITIONS                                       DAILY EVAPOTRANSPIRATION
  LAYER   OB      CB                                                   (INCHES)
               (MMHO/CM)   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET   DAY ET
    1     .10     5.98      1 .09   12 .14   23 .21   34 .27   45 .29   56 .32   67 .29   78 .28   89 .24  100 .22  111 .20
    2     .13     4.28      2 .10   13 .15   24 .22   35 .27   46 .30   57 .32   68 .29   79 .27   90 .24  101 .21  112 .20
    3     .15     3.43      3 .10   14 .16   25 .23   36 .27   47 .30   58 .32   69 .29   80 .27   91 .23  102 .21  113 .20
    4     .16     2.95      4 .10   15 .17   26 .23   37 .28   48 .30   59 .32   70 .29   81 .27   92 .23  103 .21  114 .20
    5     .17     2.53      5 .11   16 .18   27 .24   38 .28   49 .30   60 .32   71 .28   82 .26   93 .23  104 .21  115 .20
    6     .17     2.29      6 .11   17 .19   28 .25   39 .28   50 .30   61 .31   72 .28   83 .26   94 .22  105 .21  116 .20
    7     .18     1.93      7 .12   18 .20   29 .25   40 .28   51 .30   62 .30   73 .28   84 .25   95 .22  106 .21  117 .20
    8     .19     1.61      8 .12   19 .20   30 .26   41 .28   52 .31   63 .30   74 .28   85 .25   96 .22  107 .21  118 .20
    9     .19     1.39      9 .12   20 .20   31 .26   42 .29   53 .31   64 .30   75 .28   86 .25   97 .22  108 .21  119 .20
   10     .21     1.05     10 .13   21 .20   32 .27   43 .29   54 .31   65 .29   76 .28   87 .25   98 .22  109 .21  120 .19
   11     .22      .82     11 .13   22 .21   33 .27   44 .29   55 .31   66 .29   77 .28   88 .25   99 .22  110 .20  121 .00
   12     .23      .60

IMMEDIATELY PRIOR TO IRRIG 1    AFTER IRRIG INTERVAL 1    AFTER IRRIG INTERVAL 2    AFTER IRRIG INTERVAL 3    AFTER IRRIG INTERVAL 4

  SOIL   SALT   MOIST    CONC       SALT   MOIST    CONC      SALT   MOIST    CONC      SALT   MOIST    CONC      SALT   MOIST    CONC
  LAYER  T/AC   CONT    MMHO/CM     T/AC   CONT    MMHO/CM    T/AC   CONT    MMHO/CM    T/AC   CONT    MMHO/CM    T/AC   CONT    MMHO/CM
    1   .2601  .1000   5.9800      .2044  .2489   1.8892     .2646  .2313   2.6302     .2987  .2148   3.1958     .3044  .2027   3.4527
    2   .2420  .1300   4.2800      .2615  .2586   2.3296     .2903  .2456   2.6233     .3111  .2240   3.1248     .3505  .2254   3.5743
    3   .2238  .1500   3.4300      .3017  .2596   2.5693     .3120  .2485   2.9366     .3355  .2378   3.2815     .3793  .2300   3.7915
    4   .2053  .1600   2.9500      .3276  .2598   2.8492     .3398  .2485   3.1436     .3661  .2376   3.5376     .4084  .2300   4.0830
    5   .1871  .1700   2.5300      .3404  .2617   2.9906     .3544  .2513   3.2424     .3761  .2417   3.6541     .4322  .2345   4.2368
    6   .1593  .1700   2.2900      .3395  .2635   2.3622     .3543  .2542   3.2138     .3935  .2455   3.5915     .4337  .2391   4.1707
    7   .1511  .1800   1.9300      .3245  .2653   2.9118     .3746  .2571   2.9926     .3594  .2493   3.3159     .4056  .2436   3.8223
    8   .1331  .1900   1.6100      .2910  .2672   2.5037     .2991  .2599   2.6458     .3168  .2532   2.8875     .3513  .2482   3.2547
    9   .1149  .1900   1.3900      .2436  .2708   2.0673     .2490  .2657   2.1542     .2597  .2606   2.2892     .2749  .2573   2.5016
   10   .0959  .2100   1.0500      .1956  .2727   1.5650     .1888  .2685   1.5165     .1960  .2647   1.6012     .2045  .2618   1.7953
   11   .0785  .2200    .8200      .1226  .2745   1.0279     .1243  .2714   1.0527     .1277  .2685   1.0608     .1316  .2664   1.1377
   12   .0600  .2300    .6000      .0750  .2745    .6245     .0758  .2714    .6417     .0771  .2695    .6594     .0784  .2664    .6808
TOTAL  1.9212                     3.0174                    3.1759                    3.4211                    3.7598

ET PRIOR TO IRRIG 1= .00 IN    DEPTH IRRIG 1=7.56 IN      DEPTH IRRIG 2=1.10 IN      DEPTH IRRIG 3=1.72 IN      DEPTH IRRIG 4=2.30 IN
                               SALT LEAVING= .00 T/AC     SALT LEAVING= .00 T/AC     SALT LEAVING= .00 T/AC     SALT LEAVING= .00 T/AC
                               LEACHING WATER= .00 IN     LEACHING WATER= .00 IN     LEACHING WATER= .00 IN     LEACHING WATER= .00 IN
                               LEACH REQ= .00 PERCENT     LEACH REQ= .00 PERCENT     LEACH REQ= .00 PERCENT     LEACH REQ= .00 PERCENT
                               ET.INTERVAL 1=1.10 IN      ET.INTERVAL 2=1.72 IN      ET.INTERVAL 3=2.30 IN      ET.INTERVAL 4=2.73 IN
```

```
AFTER IRRIG INTERVAL  5     AFTER IRRIG INTERVAL  6     AFTER IRRIG INTERVAL  7     AFTER IRRIG INTERVAL  8     AFTER IRRIG INTERVAL  9

  SALT  MOIST   CONC          SALT  MOIST   CONC          SALT  MOIST   CONC          SALT  MOIST   CONC          SALT  MOIST   CONC
  T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM
 .2976  .1967  3.4778        .2906  .1910  3.4969        .2577  .1964  3.0159        .2473  .2112  2.4255        .2464  .2086  2.7155
 .3645  .2212  3.7385        .3664  .2172  3.8778        .3206  .2210  3.3352        .2955  .2244  3.0273        .2466  .2296  2.8697
 .4134  .2261  4.7029        .4333  .2224  4.478         .3854  .2259  3.9214        .3469  .2290  3.4815        .3275  .2338  3.2205
 .4571  .2261  4.6475        .4983  .2274  5.1501        .4587  .2259  4.6674        .4112  .2290  4.1275        .3804  .2338  3.7407
 .4340  .2310  4.9163        .5574  .2277  5.6283        .5389  .2308  5.3669        .4913  .2337  4.8354        .4511  .2380  4.3576
 .5037  .2359  4.9084        .5846  .2329  5.7700        .6060  .2358  5.9092        .5750  .2383  5.5468        .5342  .2422  5.0704
 .4728  .2408  4.5134        .5580  .2381  5.3867        .6355  .2407  6.0703        .6475  .2429  6.0893        .6187  .2464  5.7720
 .4038  .2457  3.7778        .4738  .2434  4.4758        .6064  .2456  5.6762        .6716  .2476  6.2367        .6835  .2506  6.2704
 .3111  .2555  2.7991        .3534  .2538  3.2002        .5155  .2554  4.5396        .6382  .2568  5.7124        .7015  .2590  6.2260
 .2184  .2604  1.9285        .2366  .2591  2.0996        .3879  .2603  3.4257        .5423  .2615  4.7679        .6521  .2632  5.6957
 .1380  .2653  1.1957        .1455  .2643  1.2653        .2643  .2653  2.2904        .4181  .2661  3.6122        .5536  .2674  4.7592
 .0813  .2653   .7046        .0841  .2643   .7317        .1657  .2653  1.4362        .2957  .2661  2.5544        .4316  .2674  3.7109
4.1557                      4.5820                      5.1426                      5.5766                      5.8673

DEPTH IRRIG  5=2.73 IN      DEPTH IRRIG  6=2.94 IN      DEPTH IRRIG  7=4.64 IN      DEPTH IRRIG  8=4.77 IN      DEPTH IRRIG  9=4.61 IN
SALT LEAVING= .00 T/AC      SALT LEAVING= .00 T/AC      SALT LEAVING= .11 T/AC      SALT LEAVING= .26 T/AC      SALT LEAVING= .38 T/AC
LEACHING WATER= .00 IN      LEACHING WATER= .00 IN      LEACHING WATER=1.50 IN      LEACHING WATER=1.42 IN      LEACHING WATER=1.83 IN
LEACH REQ=  .00 PERCENT     LEACH REQ=  .00 PERCENT     LEACH REQ=32.27 PERCENT     LEACH REQ=32.12 PERCENT     LEACH REQ=39.69 PERCENT
ET.INTERVAL  5=2.94 IN      ET.INTERVAL  6=3.14 IN      ET.INTERVAL  7=2.95 IN      ET.INTERVAL  8=2.78 IN      ET.INTERVAL  9=2.52 IN


AFTER IRRIG INTERVAL 10     AFTER IRRIG INTERVAL 11     AFTER IRRIG INTERVAL 12     AFTER IRRIG INTERVAL 13

  SALT  MOIST   CONC          SALT  MOIST   CONC          SALT  MOIST   CONC          SALT  MOIST   CONC
  T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM        T/AC  CONT   MMHO/CM
 .2536  .2168  2.6892        .2582  .2208  2.6884        .2628  .2236  2.7018        .2927  .2800  2.4328
 .2906  .2354  2.8377        .2933  .2382  2.8377        .2976  .2402  2.8479        .3296  .2800  2.7057
 .3264  .2391  3.1382        .3261  .2417  3.1020        .3291  .2435  3.1066        .3592  .2800  2.9490
 .3724  .2391  3.5803        .3669  .2417  3.4901        .3670  .2435  3.4643        .3965  .2800  3.2554
 .4354  .2428  4.1720        .4224  .2452  3.9610        .4174  .2468  3.8871        .4473  .2800  3.6724
 .5137  .2466  4.7900        .4930  .2487  4.5576        .4812  .2502  4.4222        .5103  .2800  4.1893
 .6021  .2503  5.5303        .5776  .2521  5.2663        .5601  .2535  5.0737        .5673  .2800  4.6522
 .6846  .2540  6.1969        .6667  .2556  5.9962        .6493  .2568  5.8129        .6757  .2800  5.5477
 .7334  .2614  6.4498        .7367  .2626  6.4500        .7304  .2634  6.3745        .7493  .2800  6.1521
 .7180  .2651  6.2253        .7538  .2661  6.5125        .7704  .2667  6.6395        .7858  .2800  6.4485
 .6445  .2689  5.5107        .7127  .2696  6.0786        .7576  .2701  6.4489        .7690  .2800  6.3118
 .5317  .2689  4.5468        .6221  .2696  5.3053        .6912  .2701  5.8837        .7003  .2800  5.7492
6.1065                      6.2296                      6.3139                      6.6025

DEPTH IRRIG 10=3.95 IN      DEPTH IRRIG 11=3.75 IN      DEPTH IRRIG 12=3.51 IN      DEPTH IRRIG 13=1.64 IN
SALT LEAVING= .33 T/AC      SALT LEAVING= .42 T/AC      SALT LEAVING= .42 T/AC      SALT LEAVING= .00 T/AC
LEACHING WATER=1.43 IN      LEACHING WATER=1.52 IN      LEACHING WATER=1.42 IN      LEACHING WATER= .00 IN
LEACH REQ=36.28 PERCENT     LEACH REQ=40.56 PERCENT     LEACH REQ=40.47 PERCENT     LEACH REQ=  .00 PERCENT
ET.INTERVAL 10=2.23 IN      ET.INTERVAL 11=2.09 IN      ET.INTERVAL 12=1.99 IN      ET.INTERVAL 13= [illegible] IN


SEASON TOTALS

    DEPTH OF IRRIGATION WATER = 45.57 INCHES
    AMOUNT OF SALT LEAVING THE ROOT ZONE = 1.93 TONS PER ACRE
    DEPTH OF LEACHING WATER = 9.52 INCHES
    LEACHING REQUIREMENT = 20.89 PERCENT
    DEPTH OF EVAPOTRANSPIRATION = 28.49 INCHES
```

## Example 2 - Short Output Prediction Version

```
INPUTS                  LAYER      PK        SFC        OT        ST
                                                               (MMHO/CM)
                          1        .17       .28       .08       5.00
                          2        .12       .28       .08       5.19
                          3        .11       .28       .08       5.36
                          4        .11       .28       .08       5.55
                          5        .10       .28       .08       5.73
                          6        .09       .28       .08       5.91
                          7        .09       .28       .08       6.09
                          8        .07       .28       .08       6.27
                          9        .05       .28       .08       6.45
                         10        .04       .28       .08       6.64
                         11        .03       .28       .08       6.82
                         12        .03       .28       .08       7.00
C = 2.00    DX= .50    L=121     KM=10     KM1= 0     CTTOL= .001


INITIAL SOIL CONDITIONS        IMMEDIATELY PRIOR TO IRRIG 1

  LAYER    OB      CH                   SALT     MOIST    CONC
                (MMHO/CM)              (T/AC)    CONT   (MMHO/CM)
    1     .10     5.98                 .2601    .1000   5.9800
    2     .13     4.28                 .2420    .1300   4.2800
    3     .15     3.43                 .2238    .1500   3.4300
    4     .16     2.95                 .2053    .1600   2.9500
    5     .17     2.53                 .1871    .1700   2.5300
    6     .17     2.29                 .1693    .1700   2.2900
    7     .18     1.93                 .1511    .1900   1.9300
    8     .19     1.61                 .1331    .1900   1.6100
    9     .19     1.39                 .1149    .1900   1.3900
   10     .21     1.05                 .0959    .2100   1.0500
   11     .22      .82                 .0785    .2200    .8200
   12     .23      .60                 .0600    .2300    .6000
                                 TOTAL 1.9212         PRIOR ET=  .00


                         DAILY EVAPOTRANSPIRATION
                                 (INCHES)
DAY ET    DAY ET    DAY ET    DAY ET    DAY ET    DAY ET    DAY ET
  1 .09    19 .20    37 .28    55 .31    73 .29    91 .23   109 .21
  2 .10    20 .20    38 .28    56 .32    74 .29    92 .23   110 .20
  3 .10    21 .20    39 .28    57 .32    75 .28    93 .23   111 .21
  4 .10    22 .21    40 .28    58 .32    76 .29    94 .22   112 .20
  5 .11    23 .21    41 .28    59 .32    77 .28    95 .22   113 .21
  6 .11    24 .22    42 .29    60 .32    78 .29    96 .22   114 .21
  7 .12    25 .23    43 .29    61 .31    79 .27    97 .22   115 .20
  8 .12    26 .23    44 .29    62 .30    80 .27    98 .22   116 .20
  9 .12    27 .24    45 .29    63 .30    81 .27    99 .22   117 .20
 10 .13    28 .25    46 .30    64 .30    82 .26   100 .22   118 .20
 11 .13    29 .25    47 .30    65 .29    83 .26   101 .21   119 .20
 12 .14    30 .26    48 .30    66 .29    84 .25   102 .21   120 .19
 13 .15    31 .26    49 .30    67 .29    85 .25   103 .21   121 .00
 14 .16    32 .27    50 .30    68 .29    86 .25   104 .21
 15 .17    33 .27    51 .30    69 .29    87 .25   105 .21
 16 .18    34 .27    52 .31    70 .29    88 .25   106 .21
 17 .19    35 .27    53 .31    71 .28    89 .24   107 .21
 18 .20    36 .27    54 .31    72 .28    90 .24   108 .21
```

```
  AFTER      SALT        SALT      WATER   LEACHING   LEACHING     ET FOR
  IRRIG    EXISTING    LEAVING    APPLIED    WATER      REQ.      INTERVAL
INTERVAL    (T/AC)     (T/AC)      (IN)      (IN)    (PERCENT)      (IN)
    1        3.02        .00       7.55       .00        .00       1.1[illegible]
    2        3.19        .00       1.10       .00        .00       1.72
    3        3.43        .00       1.72       .00        .00       2.3[illegible]
    4        3.76        .00       2.30       .00        .00       2.77
    5        4.15        .00       2.73       .00        .00       2.9[illegible]
    6        4.59        .10       2.94       .00        .0[illegible]       3.10
    7        5.14        .11       4.60      1.59      32.27       2.[illegible]
    8        5.59        .26       4.77      1.82      38.12       2.[illegible]
    9        5.87        .38       4.61      1.83      39.6[illegible]       2.[illegible]
   10        6.11        .33       3.35      1.47      36.2[illegible]       2.[illegible]
   11        6.23        .42       3.75      1.52      40.5[illegible]       2.[illegible]
   12        6.31        .42       3.51      1.42      40.47       1.[illegible]
   13        6.60        .00       1.95       .00        .00        .00
  SEASON     6.60       1.93      45.57     [illegible].52      21.89      23.4[illegible]
```

# FORTRAN Listing of Evaluation Version

```
      C       THIS VERSION DOES NOT ITERATE ON DEPTH APPLIED, INSTEAD BOTH DEPTH AND
      C                                      CONCENTRATION OF IRRIGATION WATER ARE INPUT
      C       UTAH STATE UNIVERSITY
      C       PROJECT  WG 84 FWPCA
      C       DEFINITIONS
      C       C    IS THE CONCENTRATION OF IRRIGATION WATER  MMHO/CM
      C       CB   IS THE AVERAGE INITIAL CONCENTRATION OF THE SOIL SOLUTION  MMHO/CM
      C       CE   IS THE CONCENTRATION OF WATER ENTERING A LAYER  MMHO/CM
      C       CF   IS THE FINAL COCENTRATION OF SOIL SOLUTION  MMHO/CM, JUST BEFORE
      C              THE NEXT IRRIGATION
      C       CFC IS THE CONCENTRATION AT FIELD CAPACITY
      C       CL   IS THE CONCENTRATION OF WATER LEAVING A LAYER   MMHO/CM
      C       CT   IS THE  CRITICAL CONCENTRATION OF SOIL SOLUTION  MMHO/CM
      C       DX   IS THE THICKNESS OF EACH LAYER FT.
      C       DD   IS THE DEPTH APPLIED/IRRIGATION
      C       DE   IS THE DEPTH OF WATER ENTERING A LAYER
      C       DL   IS THE DEPTH OF WATER LEAVING A LAYER
      C       ET   IS THE EVAPOTRANSPIRATION INCHES
      C       I    DESIGNATES A PARTICULAR LAYER
      C       ICHECK INDICATES WHICH FIELD DATA CHECKPOINT IS APPLICABLE
      C       J    DESIGNATES A PARTICULAR IRRIGATION
      C       KF   IS THE FIRST DAY OF A GIVEN IRRIGATION INTERVAL
      C       KK   IS THE LAST DAY OF A GIVEN IRRIGATION INTERVAL
      C       KM   IS THE NUMBER OF DAYS IN THE IRRIGATION INTERVAL
      C       KM1 IS THE NUMBER OF DAYS FROM INITIAL SAMPLING TO FIRST IRRIGATION
      C       L    IS THE LENGTH IN DAYS OF THE PERIOD UNDER STUDY
      C       N    IS THE NUMBER OF LAYERS IN THE ROOT ZONE
      C       NB   IS THE NUMBER OF THE BLOCK BEING IRRIGATED
      C       NI   IS THE NUMBER OF IRRIGATIONS DURING THE PERIOD UNDER STUDY
      C       NP   IS THE NUMBER OF PERIODS BEING RUN
      C       OB   IS THE INITIAL MOISTURE CONTENT  VOLUMETRIC
      C       OF   IS THE FINAL MOISTURE CONTENT JUST BEFORE THE NEXT IRRIGATION
      C       OFC IS THE MOISTURE CONTENT AT FIELD CAPACITY VOLUMETRIC
      C       OT   IS THE CRITICAL MOISTURE CONTENT  VOLUMETRIC
      C       RK   IS THE PERCENTAGE OF MOISTURE EXTRACTED FROM A SOIL LAYER
      C       WTPA IS THE AMOUNT OF SALT IN A GIVEN LAYER
            DIMENSION CB(20),OB(20),OFC(20),OT(20),CT(20),RK(20),WTPA(20),DE(2
           10),CE(20),DL(20),CL(20),OF(20),CF(20),CAI(20),ET(150),CBT(20),
           2ET1(150),WTPA1(20),CFT(20),C(30),DD(30),KM(30),OBT(20),OFT(20),
           3OAI(20)
            DATA AST,BLANK/1H*,1H /
            READ(5,2)NP
          2 FORMAT(I2)
            ICOUNT=1
          1 READ(5,100) DX,N,NB,ICHECK,NI,KM1
        100 FORMAT(F3.0,5I2)
            READ(5,101)(DD(J),J=1,NI)
            READ(5,101)(C(J),J=1,NI)
            READ(5,550)(KM(J),J=1,NI)
        550 FORMAT(40I2)
            IF(ICHECK.NE.1)GO TO 400
            READ(5,401)(OB(I),I=1,N)
        401 FORMAT(13F6.0)
            READ(5,401)(CB(I),I=1,N)
            READ(5,101)(RK(I),I=1,N)
            READ(5,101)(OFC(I),I=1,N)
            READ(5,101)(OT(I),I=1,N)
            READ(5,101)(CT(I),I=1,N)
        101 FORMAT(16F5.0)
        400 L=KM1
            DO 500 J=1,NI
        500 L=L+KM(J)
          3 READ(5,102)(ET(K),K=1,L)
        102 FORMAT(20F4.2)
            J=1
            KF=1+KM1
            KK=KM(J)+KM1
            WRITE(6,402)NB,ICHECK
        402 FORMAT('1INPUTS',13X,'LAYER      RK       OFC       OT        CT'/' B
           1LOCK',I2,'.',I2,42X,'(MMHO/CM)')
            WRITE(6,103)(I,RK(I),OFC(I),OT(I),CT(I),I=1,N)
        103 FORMAT(1H ,20X,I2,F9.2,F9.3,F9.2,F10.2)
            WRITE(6,578)
        578 FORMAT('0 ')
            WRITE(6,107)
        107 FORMAT(' INITIAL SOIL CONDITIONS          DAILY EVAPOTRANSPIRATION'/'
           1   LAYER   OB     CB                        (INCHES)'/1H ,13X,'(MMHO/CM
     2     DAY ET   DAY ET   DAY ET   DAY ET')
  108 FORMAT(I6,F7.3,F8.2,4X,4(I5,F4.2))
      NX=(L-1)/4+1
      DO 404 I=1,N
      WRITE(6,108) I,OB(I),CB(I),(LL,ET(LL),LL=I,L,NX)
  404 IF(I.EQ.NX)GO TO 405
  801 FORMAT(25X,4(I5,F4.2))
      II=N+1
      DO 800 M=II,NX
  800 WRITE(6,801)(LL,ET(LL),LL=M,L,NX)
      GO TO 406
  405 IF(I.EQ.N) GO TO 406
      I=I+1
      WRITE(6,109)(II,OB(II),CB(II),II=I,N)
  109 FORMAT(I6,F7.3,F8.2)
  406 NII=NI+1
      DO 4 M=1,NII
    4 ETT(M)=0.0
      SAM=0.0
      DO 14 I=1,N
      D=(OFC(I)-OB(I))*DX*12.0
   14 SAM=SAM+D
      IF(KM1.EQ.0)GO TO 23
      DO 5 I=1,KM1
    5 ETT(1)=ETT(1)+ET(I)
      SAM=SAM+ETT(1)
      DO 380 I=1,N
      OBS=OB(I)
      CBS=CB(I)
      OB(I)=OB(I)-(RK(I)*ETT(1))/(DX*12.0)
      IF(OB(I).GE.0.) GO TO 380
      OB(I)=0.
  380 CB(I)=OBS*CBS/OB(I)
   23 TSPA=0.0
      IF(J.NE.1) GO TO 575
      DO 13 I=1,N
      WTPA(I)=OB(I)*DX*0.8704*CB(I)
   13 TSPA=TSPA+WTPA(I)
      GO TO 217
  575 SAM=0.0
      DO 505 I=1,N
      D=(OFC(I)-OB(I))*DX*12.0
  505 SAM=SAM+D
  217 DO 16 I=KF,KK
   16 ETT(J+1)=ETT(J+1)+ET(I)
      CE(1)=C(J)
   22 DE(1)=DD(J)
      DO 15 I=1,N
      DFC=OFC(I)*12.0*DX
      DEX=OB(I)*DX*12.0
      DTOTAL=DE(I)+DEX
      IF(DTOTAL.GT.DFC)GO TO 200
      DAT=DTOTAL
      OAI(I)=DAT/(12.*DX)
      GO TO 62
  200 OAI(I)=OFC(I)
      DL(I)=DE(I)-(DFC-DEX)
      ER=DL(I)/DFC
      DEX=OB(I)
      CL(I)=PF(DEX,ER)*(DE(I)*CE(I)+DEX*CB(I))/DL(I)
      CAI(I)=(DEX*CB(I)+DE(I)*CE(I)-DL(I)*CL(I))/DFC
      GO TO 66
   62 DL(I)=0.
      CL(I)=0.
      CAI(I)=(DEX*CB(I)+DE(I)*CE(I))/DAT
   66 CE(I+1)=CL(I)
   15 DE(I+1)=DL(I)
      IF((ETT(J)+0.0001).GT.DD(J)) GO TO 67
      WLPA=DL(N)*CL(N)*0.8704/12.0
      GO TO 68
   67 WLPA=0.0
   68 DO 17 I=1,N
      OF(I)=OAI(I)-(RK(I)*ETT(J+1))/(DX*12.0)
      CF(I)=OAI(I)*CAI(I)/OF(I)
      IF(OF(I).GE.0.) GO TO 17
      OF(I)=0.
   17 CONTINUE
      TSPA1=0.0
      DO 323 I=1,N
      WTPA1(I)=OF(I)*DX*.8704*CF(I)
  323 TSPA1=TSPA1+WTPA1(I)
  417 DO 413 I=1,N
      IF(CF(I).GT.CT(I))GO TO 417
      CFT(I)=BLANK
      GO TO 375
  417 CFT(I)=AST
  375 IF(QF(I).LT.QT(I)) GO TO 376
      QFT(I)=BLANK
      GO TO 413
  376 QFT(I)=AST
  413 CONTINUE
      IF(J.NE.1) GO TO 506
      DO 377 I=1,N
      IF(CB(I).GT.CT(I)) GO TO 415
      CBT(I)=BLANK
      GO TO 416
  415 CBT(I)=AST
  416 IF(QB(I).LT.QT(I)) GO TO 378
      QBT(I)=BLANK
      GO TO 377
  378 QBT(I)=AST
  377 CONTINUE
      WRITE(6,403)C(1),DX,KM(1),KM1
  403 FORMAT('1C= ',F5.2,4X,'DX= ',F8.2,4X,'KM= ',I2,4X,'KM1= ',I2)
      WRITE(6,408)J,J
  408 FORMAT('0CONDITIONS IMMEDIATELY PRIOR      CONDITIONS AFTER IRRIGAT
     1ION'/' TO IRRIGATION',I3,17X,'INTERVAL',I3/'0  SOIL  SALT  MOIST
     2  CONC         SALT  MOIST   CONC'/'   LAYER T/AC  CONT   MMHO/CM
     3     T/AC  CONT   MMHO/CM')
      WRITE(6,414)(I,WTPA(I),QB(I),QBT(I),CB(I),CBT(I),WTPA1(I),QF(I),QF
     1T(I),CF(I),CFT(I),I=1,N)
  414 FORMAT(1H ,I6,2F7.4,A1,F7.4,A1,F10.4,F7.4,A1,F7.4,A1)
      WRITE(6,311)TSPA,TSPA1
  311 FORMAT(' TOTAL',F8.4,19X,F7.4/)
      GO TO 700
  506 IF(J.EQ.3.OR.J.EQ.5.OR.J.EQ.7.OR.J.EQ.9.OR.J.EQ.11)GO TO 508
      WRITE(6,507) NB,ICHECK,C(J),KM(J)
  507 FORMAT(' BLOCK',I2,'-',I2,7X,'C =',F5.2,'      KM =',I2/)
      GO TO 709
  508 WRITE(6,552)NB,ICHECK,C(J),KM(J)
  552 FORMAT('1BLOCK',I2,'-',I2,7X,'C =',F5.2,'      KM =',I2/)
  709 WRITE(6,708)J
  708 FORMAT(' CONDITIONS AFTER IRRIG INTERVAL',I3/'0   SOIL  SALT  MOIS
     1T   CONC'/'    LAYER T/AC  CONT   MMHO/CM')
      WRITE(6,714)(I,WTPA1(I),QF(I),QFT(I),CF(I),CFT(I),I=1,N)
  714 FORMAT(1H ,I6,2F7.4,A1,F7.4,A1)
      WRITE(6,711)TSPA1
  711 FORMAT(' TOTAL',F8.4/)
  700 WRITE(6,312)J,DD(J)
  312 FORMAT(' DEPTH OF WATER APPLIED FOR IRRIGATION',I3,' =',F5.2,' INC
     1HES')
      WRITE(6,313)WLPA
  313 FORMAT(' AMOUNT OF SALT ENTERING SATURATED ZONE =',F8.2,' TONS PER
     1 ACRE')
      CHL=DD(J)-SAM
      WRITE(6,315)CHL
  315 FORMAT(' LEACHING WATER =',F6.2,' INCHES')
      RL=CHL*100.0/DD(J)
      WRITE(6,316)RL
  316 FORMAT(' LEACHING PERCENTAGE = ',F7.2,' PERCENT')
      IF(J.NE.1.OR.KM1.EQ.0)GO TO 777
      WRITE(6,418) J,ETT(1)
  418 FORMAT(' ET PRIOR TO IRRIGATION',I3,' =',F5.2,' INCHES')
  777 WRITE(6,314)J,ETT(J+1)
  314 FORMAT(' TOTAL ET FOR IRRIGATION INTERVAL',I3,' =',F5.2,' INCHES'/
     1//)
  511 KF=KF+KM(J)
      J=J+1
      KK=KK+KM(J)
      DO 501 I=1,N
      QB(I)=QF(I)
  501 CB(I)=CF(I)
      IF(J.LE.NI) GO TO 23
      IF(ICOUNT.EQ.NP)GO TO 512
      ICOUNT=ICOUNT+1
      GO TO 1
  512 STOP
      END
```

```
000          FUNCTION PF(QEX,ER)
000          DIMENSION A(5,3),B(9)
000          DATA((A(I,J),J=1,3),I=1,5)/-.65575,7.0434,-20.536,.45808,-7.1187,
000         X22.549,-.094719,1.4081,-11.734,-.019777,-.30143,2.5471,.030781,
000         X-2.4902,15.651/
000          DO 10 I=1,5
000       10 B(I)=A(I,1)+A(I,2)*QEX+A(I,3)*QEX**2
000          IF(ER.LT.0.2) GO TO 1
000          IF(ER.GE.0.2.AND.ER.LE.3.) GO TO 2
000        3 PFLOG=B(1)+B(2)*ALOG(3.)+B(3)*(ALOG(3.))**2+B(4)*(ALOG(3.))**3+B(5
000         X)/3.
000          PF3=EXP(PFLOG)
000          B(9)=B(2)+2.*B(3)*ALOG(3.)+3.*B(4)*(ALOG(3.))**2-B(5)/3.
000          B(8)=PF3/3.**B(9)
000          PF=B(8)*ER**B(9)
000          IF(PF.GT.1.)  PF=1.
000          GO TO 4
000        1 PFLOG=B(1)+B(2)*ALOG(.2)+B(3)*(ALOG(.2))**2+B(4)*(ALOG(.2))**3+B(5
000         X)/.2
000          PF2=EXP(PFLOG)
000          B(7)=B(2)+2.*B(3)*ALOG(.2)+3.*B(4)*(ALOG(.2))**2-B(5)/.2
000          B(6)=PF2/.2**B(7)
000          PF=B(6)*ER**B(7)
000          GO TO 4
000        2 PFLOG=B(1)+B(2)*ALOG(ER)+B(3)*(ALOG(ER))**2+B(4)*(ALOG(ER))**3+B(5
000         X)/ER
000          PF=EXP(PFLOG)
000        4 CONTINUE
000          RETURN
000          END
```

Example 3 - Sample Output Evaluation Version

```
INPUTS              LAYER     RK      QFC      QT       CT
BLOCK S. 1                                             (MMHO/CM)
                      1       .41     .311     .08      4.00
                      2       .30     .311     .08      5.00
                      3       .19     .311     .08      6.00
                      4       .10     .311     .08      7.00
                      5       .00     .311     .00    100.00
                      6       .00     .319     .00    100.00
                      7       .00     .330     .00    100.00
                      8       .00     .351     .00    100.00
                      9       .00     .385     .00    100.00
                     10       .00     .406     .00    100.00
                     11       .00     .415     .00    100.00

INITIAL SOIL CONDITIONS        DAILY EVAPOTRANSPIRATION
 LAYER    QR      CR                    (INCHES)
               (MMHO/CM)      DAY ET   DAY ET   DAY ET   DAY ET
   1     .181    4.71          1 .21   12 .28   23 .22   34 .23
   2     .194    4.71          2 .19   13 .26   24 .24   35 .23
   3     .224    3.09          3 .15   14 .25   25 .23   36 .27
   4     .246    3.09          4 .00   15 .26   26 .26   37 .31
   5     .240    2.94          5 .13   16 .26   27 .00   38 .34
   6     .246    2.94          6 .20   17 .26   28 .00   39 .31
   7     .264    3.23          7 .00   18 .26   29 .00   40 .25
   8     .286    3.23          8 .00   19 .30   30 .00   41 .22
   9     .314    3.14          9 .20   20 .37   31 .24   42 .17
  10     .345    3.14         10 .24   21 .35   32 .22   43 .06
  11     .379    2.84         11 .28   22 .27   33 .25

  C=  1.27    DX=   .50    KM= 11    KM1=  7

  CONDITIONS IMMEDIATELY PRIOR       CONDITIONS AFTER IRRIGATION
  TO IRRIGATION  1                   INTERVAL  1

    SOIL   SALT   MOIST    CONC          SALT   MOIST    CONC
    LAYER  T/AC   CONT    MMHO/CM        T/AC   CONT    MMHO/CM
      1   .3710  .1209   7.0533*        .3031  .1368   5.0931*
      2   .3977  .1500   6.0916*        .4845  .1835   6.0675*
      3   .3012  .1961   3.5290         .5097  .2303   5.0871
      4   .3308  .2313   3.2859         .3797  .2228   3.9150
      5   .3071  .2400   2.9400         .3071  .2400   2.9400
      6   .3148  .2460   2.9400         .3148  .2460   2.9400
      7   .3711  .2640   3.2300         .3711  .2640   3.2300
      8   .4020  .2860   3.2300         .4020  .2860   3.2300
      9   .4291  .3140   3.1400         .4291  .3140   3.1400
     10   .4715  .3450   3.1400         .4715  .3450   3.1400
     11   .4684  .3790   2.8400         .4684  .3790   2.8400
  TOTAL  4.1647                        4.4410

  DEPTH OF WATER APPLIED FOR IRRIGATION  1 = 3.00 INCHES
  AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
  LEACHING WATER = -2.93 INCHES
  LEACHING PERCENTAGE =  -97.73 PERCENT
  ET PRIOR TO IRRIGATION  1 =   .88 INCHES
  TOTAL ET FOR IRRIGATION INTERVAL  1 = 2.55 INCHES
```

```
BLOCK 5. 1          C =  .98      KM =10

CONDITIONS AFTER IRRIG INTERVAL   2

    SOIL   SALT   MOIST    CONC
    LAYER  T/AC   CONT    MMHO/CM
      1   .2384   .1579   3.4689
      2   .4703   .1990   5.4306*
      3   .6336   .2401   6.0642*
      4   .5157   .2737   4.3299
      5   .3394   .2693   2.8955
      6   .3148   .2460   2.9400
      7   .3711   .2640   3.2300
      8   .4020   .2860   3.2300
      9   .4291   .3140   3.1400
     10   .4715   .3450   3.1400
     11   .4684   .3790   2.8400
TOTAL   4.6543

DEPTH OF WATER APPLIED FOR IRRIGATION  2 = 3.00 INCHES
AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
LEACHING WATER = -2.48 INCHES
LEACHING PERCENTAGE =  -82.73 PERCENT
TOTAL ET FOR IRRIGATION INTERVAL  2 = 2.24 INCHES



BLOCK 5. 1          C = 1.53      KM = 9

CONDITIONS AFTER IRRIG INTERVAL   3

    SOIL   SALT   MOIST    CONC
    LAYER  T/AC   CONT    MMHO/CM
      1   .2598   .1914   3.1183
      2   .4582   .2235   4.7109
      3   .6939   .2556   6.2381*
      4   .6424   .2818   5.2373
      5   .4228   .3110   3.1241
      6   .3614   .3190   2.6031
      7   .3777   .2760   3.1448
      8   .4020   .2860   3.2300
      9   .4291   .3140   3.1400
     10   .4715   .3450   3.1400
     11   .4684   .3790   2.8400
TOTAL   4.9872

DEPTH OF WATER APPLIED FOR IRRIGATION  3 = 3.00 INCHES
AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
LEACHING WATER = -1.72 INCHES
LEACHING PERCENTAGE =  -57.40 PERCENT
TOTAL ET FOR IRRIGATION INTERVAL  3 = 1.75 INCHES
```

```
BLOCK S. 1         C = 1.00      KM = 6

CONDITIONS AFTER IRRIG INTERVAL  4

   SOIL   SALT   MOIST    CONC
   LAYER  T/AC   CONT    MMHO/CM
     1   .3022   .2198   3.1743
     2   .4760   .1748   6.2589*
     3   .6939   .2128   7.4911*
     4   .6424   .2593   5.6917
     5   .4228   .3110   3.1241
     6   .3614   .3190   2.6031
     7   .3777   .2760   3.1448
     8   .4020   .2860   3.2300
     9   .4291   .3140   3.1400
    10   .4715   .3450   3.1400
    11   .4684   .3790   2.8400
TOTAL   5.0474

DEPTH OF WATER APPLIED FOR IRRIGATION  4 =  .83 INCHES
AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
LEACHING WATER = -2.64 INCHES
LEACHING PERCENTAGE = -318.31 PERCENT
TOTAL ET FOR IRRIGATION INTERVAL  4 = 1.35 INCHES




INPUTS                LAYER      RK        QFC        QT         CT
BLOCK S. 2                                                   (MMHO/CM)
                        1        .41       .311       .08        4.00
                        2        .50       .311       .08        5.00
                        3        .19       .311       .08        6.00
                        4        .10       .311       .08        7.00
                        5        .00       .311       .00      100.00
                        6        .00       .319       .00      100.00
                        7        .00       .330       .00      100.00
                        8        .00       .351       .00      100.00
                        9        .00       .385       .00      100.00
                       10        .00       .406       .00      100.00
                       11        .00       .415       .00      100.00

INITIAL SOIL CONDITIONS         DAILY EVAPOTRANSPIRATION
 LAYER    QB       CB                    (INCHES)
                (MMHO/CM)       DAY ET    DAY ET    DAY ET    DAY ET
   1     .219     3.17           1 .06    11 .29    21 .14    31 .17
   2     .175     6.26           2 .12    12 .29    22 .13    32 .19
   3     .213     7.49           3 .14    13 .27    23 .11    33 .00
   4     .259     5.69           4 .13    14 .00    24 .18    34 .21
   5     .311     3.12           5 .12    15 .20    25 .22    35 .00
   6     .319     2.60           6 .15    16 .18    26 .11    36 .22
   7     .276     3.14           7 .19    17 .17    27 .20    37 .19
   8     .286     3.23           8 .23    18 .18    28 .07
   9     .314     3.14           9 .24    19 .18    29 .22
  10     .345     3.14          10 .26    20 .18    30 .17
  11     .379     2.84
```

```
C =   .94    DX=  .50    KM= 12    KM1= 14

CONDITIONS IMMEDIATELY PRIOR      CONDITIONS AFTER IRRIGATION
TO IRRIGATION  1                  INTERVAL  1

   SOIL   SALT   MOIST    CONC          SALT   MOIST    CONC
   LAYER  T/AC   CONT    MMHO/CM        T/AC   CONT    MMHO/CM
     1   .3022  .0486* 14.2876*        .2276  .1757   2.9769
     2   .4760  .0503* 21.7660*        .5018  .2120   5.4391*
     3   .6939  .1340  11.8996*       1.0153  .2148  10.8613*
     4   .6424  .2178   6.7760         .6424  .1848   7.9858*
     5   .4228  .3110   3.1241         .4228  .3110   3.1241
     6   .3614  .3190   2.6031         .3614  .3190   2.6031
     7   .3777  .2760   3.1448         .3777  .2760   3.1448
     8   .4020  .2860   3.2300         .4020  .2860   3.2300
     9   .4291  .3140   3.1400         .4291  .3140   3.1400
    10   .4715  .3450   3.1400         .4715  .3450   3.1400
    11   .4684  .3790   2.8400         .4684  .3790   2.8400
TOTAL   5.0974                        5.3201

DEPTH OF WATER APPLIED FOR IRRIGATION  1 = 4.00 INCHES
AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
LEACHING WATER = -2.49 INCHES
LEACHING PERCENTAGE =  -62.05 PERCENT
ET PRIOR TO IRRIGATION  1 = 2.49 INCHES
TOTAL ET FOR IRRIGATION INTERVAL  1 = 1.98 INCHES


BLOCK 5. 2        C =  .86    KM = 9

CONDITIONS AFTER IRRIG INTERVAL  2

   SOIL   SALT   MOIST    CONC
   LAYER  T/AC   CONT    MMHO/CM
     1   .1866  .2270   1.8892
     2   .4107  .2495   3.7825
     3   .9182  .2721   7.7549*
     4   .9343  .2905   7.3897*
     5   .5300  .3110   3.9160
     6   .3683  .3190   2.6527
     7   .3882  .3193   2.7936
     8   .4020  .2860   3.2300
     9   .4291  .3140   3.1400
    10   .4715  .3450   3.1400
    11   .4684  .3790   2.8400
TOTAL   5.5072

DEPTH OF WATER APPLIED FOR IRRIGATION  2 = 3.00 INCHES
AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
LEACHING WATER = -1.46 INCHES
LEACHING PERCENTAGE =  -48.73 PERCENT
TOTAL ET FOR IRRIGATION INTERVAL  2 = 1.23 INCHES
```

```
BLOCK 5. 2        C = .01     KM = 2

CONDITIONS AFTER IRRIG INTERVAL  3

   SOIL   SALT   MOIST    CONC
   LAYER  T/AC   CONT    MMHO/CM
     1   .1869   .2789   1.5400
     2   .4107   .2290   4.1211
     3   .9182   .2591   8.1436*
     4   .9343   .2837   7.5678*
     5   .5300   .3110   3.3160
     6   .3683   .3190   2.6527
     7   .3882   .3193   2.7936
     8   .4020   .2860   3.2300
     9   .4291   .3140   3.1400
    10   .4715   .3450   3.1400
    11   .4684   .3790   2.8400
TOTAL   5.5076

DEPTH OF WATER APPLIED FOR IRRIGATION  3 =  .48 INCHES
AMOUNT OF SALT ENTERING SATURATED ZONE = .00 TONS PER ACRE
LEACHING WATER = -2.21 INCHES
LEACHING PERCENTAGE = -460.83 PERCENT
TOTAL ET FOR IRRIGATION INTERVAL  3 =  .41 INCHES
```

# APPENDIX B

## DETAILED MODEL

### FORTRAN Listing of Water Model

```
C******************************************************************************
             SALT AND WATER FLOW, 1972
@FOR,I  MAIN,MAIN
C       PROGRAM-SOIL WATER,SALT,FLOW WITH PLANT UPTAKE.
C       PROGRAM OF FEB. 29,1972
C       CONQ IS  LARGEST WATERCONTENT CHANGE ALLOWED EACH COMPUTATION
C       HWET IS PRESSURE OF HIGHEST POSSIBLE WATER CONTENT
C       V IS BOUNDARY CONDITIONS AT TOP AND TIMES CONDITIONS APPLY
C       DELT IS TIME INCREMENT TO START WITH AND LOWEST TO USE
C       CONQ IS SMALLEST WATERCONTENT CHANGE ALLOWED EACH COMPUTATION
C       GRAVY IS GRAVITY COMPONENT USUALLY THE SAME AS DELX
C       DELW IS WATER CONTENT DIFFERENCE CORRESPONDING TO TABLE INCREMENTS
C       T IS WATER CONTENT TABLE  HAS EQUAL SPACED INCREMENTS
C       TIME IS CUMULATIVE TIME AT START OF COMPUTATION
C       TT IS 1.0 FOR LAASONEN AND 0.5 FOR CRANK NICHOLSON
C       CUMT IS TIME AT END OF COMPUTATION
C-----TAA=1, FOR ZERO FLUX AT BOTTOM,TAA=0 FOR H(KK) CONSTANT              A    6
C         FROM G(I) OR H(I)=G(I)
C       CTM IS LOWEST VALUE OF DELT PERMITTED--IF AS LOW STOPS
C       HDRY IS PRESSURE OF LOWEST POSSIBLE WATER CONTENT
C       PP IS PRESSURE TABLE(WETTING)STARTING WITH LOWEST PRESSURE
C       D IS CONDUCTIVITY TABLE STARTING WITH LOWEST WATER CONTENT VALUE
C       DD SAME AS ABOVE EXCEPT STARTS FROM WETTING
C       C IS WATER CAPACITY AS A FUNCTION OF DEPTH  BEGINNING AT TOP
C       DELX IS DEPTH INCREMENT
C       W IS WATER CONTENT  AS A FUNCTION OF DEPTH  BEGINNING AT TOP
C       H IS WATER PRESSURE AS A FUNCTION OF DEPTH  BEGINNING AT TOP
C       WATL IS LOWEST POSSIBLE WATER CONTENT
C       WATH IS HIGHEST POSSIBLE WATER CONTENT
C       CB IS A CONSTANT TO MULTIPLY D ARRAY BY--USUALLY 1.0
C-----K IS NO. OF DELX INCREMENTS,MM NO. OF TIMES H,W PRINTED,KIT NO.OF   A   12
C-----START HERE FOR A NEW PROGRAM                                         A   13
C-----MI IS TO PRINT H,W ARRAYS EACH ITER.,IER NO. OF V ELEMENTS           A   14
C       HROOT IS THE ACTUAL ROOT WATER POTENTIAL
C       BB REPRESENTS PLANT UPTAKE ADDITIONS
C       HLOW IS THE MINIMUM ROOT POTENTIAL ALLOWED
C       HHI IS THE MAXIMIM  ROOT POTENTIAL ALLOWED
C       ET IS THE POTENTIAL EVAPOTRANSPIRATION,ALWAYS NEGATIVE
C       WEDD IS THE WATER FLOW RATE AT THE SURFACE
C       ETPL IS THE POTENTIAL TRANSPIRATION,ALWAYS NEGATIVE
C       TET IS THE BOUNDARY POTENTIAL ET,ALWAYS NEGATIVE,LTV ARRAY
C******DD,H,G'Y'W'RDF'A(SE(SS'SD'ARRAYS ARE OF SAME DIMENSIONS AT LEAST=KK
C******SF'TET'V ARRAYS ARE OF SAME DIMENSIONS AT LEAST=IER
C******P'D'T'ARE OF EQUAL DIMENSIONS,=60 AT MOST
C*******************************************************************************
      DIMENSION DD(25),H(25),G(25),Y(25),W(25),RDF(25),A(25),SE(25)
      DIMENSION SS(25),SD(25),C(25),B(25),F(25),F(25)
      DIMENSION SF(65),TET(65),V(65)
      DIMENSION P(50),D(50),T(50)
      WRITE(6,8765)
 8765 FORMAT(1H1,25X,61('*'))
      WRITE(6,8766)
 8766 FORMAT(1H ,25X,'*ROOT DEPTH NORMALT.. EVAPRATION =0.1 EVAPOTRANSP
     1IRATION.  *')
      WRITE(6,9999)
9999  FORMAT(1H,25X,'STAA=0.0    UPWARD WATER FLOW..FIELD DATA
     1HLOW=-15 BARS. CROP 1.1971')
      WRITE(6,8767)
 8767 FORMAT(1H ,25X,61('*'))
```

```
C***********************************************************************
      READ 163, ML
      LMM=0                                                           A   9
1     LMM=LMM+1                                                       A  11
      READ(5,163)K,MM,IER,NB,ND                                       A  10
      KK=K+1
      READ(5,165) (TET(I),I=1,IER)                                    A  18
      READ(5,165) (RDF(I),I=1,KK)
      KC=1
      WFDD=-.009
      ET=TET(1)
      LL=MM
      READ(5,165)(P(I),I=1,ND)                                        A  19
      READ(5,165)(D(I),I=1,ND)
      READ 165, (W(I),I=1,KK)
      READ 165, (V(I),I=1,IER)                                        A  25
      READ 165, DELX,DETT,GRAVY,CONO,DELW,TIME                        A  26
      READ 165, TT,CUMT,TAA,HLOW,HHI,RRES
      READ 165, HDRY,HWET,WATL,WATH,CB
      READ 165,(SF(I),I=1,IER)
      READ 165, (SF(I),I=1,KK)
      WRITE (6,169)
      WRITE(6,163) K,MM,IER,NB,ND
      P(1)=P(1)*1.0E+03
      T(1)=0.0
      DO 900 I=2,ND                                                   A  38
      T(I)=DELW+T(I-1)
900   P(I)=P(I)*1.0E+03
      READ 165,(DD(I),I=1,KK)
      SE(1)=SF(1)
      SMAX=5.0
      CWFLX=0.0
      EOR=V(1)
      DELT=DETT                                                       A  74
      TW=1.0-TT
      TAB=1.0-TAA                                                     A  75
      YMAX=WATH                                                       A  77
      DO 14 I=1,KK                                                    A  82
      SS(I)=SF(I)
      SO(I)=SE(I)*W(I)
14    Y(I)=W(I)
      PIT=0.0                                                         A  87
      DO 15 I=2,K                                                     A  89
   15 PIT=W(I)*(DD(I+1)-DD(I-1))/2.+PIT
      WRITE (6,170)
      TW=D(1)
      D(1)=(D(1)*(P(2)-P(1)))*CB
      J=(W(1)-T(1))/DELW+1.0                                          A  39
      H(1)=(P(J+1)-P(J))*(W(1)-T(J))/DELW+P(J)
      G(1)=H(1)
      C(1)=DELW/(P(J+1)-P(J))
      WRITE ( 6,166) T(1),P(1),TW,D(1),C(1),DD(1),W(1),H(1),RDF(1),SF(1)
      DO 3 I=2,KK
      TW=D(I)
      D(I)=D(I)*(P(I)-P(I-1))*CB+D(I-1)                               A  41
      J=(W(I)-T(1))/DELW+1.0
      H(I)=(P(J+1)-P(J))*(W(I)-T(J))/DELW+P(J)
      C(I)=DELW/(P(J+1)-P(J))
      G(I)=H(I)
      WRITE ( 6,166) T(I),P(I),TW,D(I),C(I),DD(I),W(I),H(I),RDF(I),SF(I)   A  86
3     CONTINUE
      N=KK+1
      DO 2 I=N,ND
      TW=D(I)
      D(I)=D(I)*(P(I)-P(I-1))*CB+D(I-1)
2     WRITE (6,166) T(I),P(I),TW,D(I)
C***********************************************************************
C     D IS NOW DIFFUSIVITY TIMES DELW NOT CONDUCTIVITY
      WRITE (6,179)
      DO 5 I=2,IER,2
```

```
5     WRITE (6,166) V(I),V(I-1),TFT(I-1),SF(I-1)
      WRITE (6,180)
      WRITE (6,166) DFLX,DFTT,GRAVY,CONO,DFLW,TIME
      WRITE (6,181)
      WRITE (6,166) TT,CUMT,TAA,HLOW,HHI,RRES
      WRITE (6,172)
      WRITE (6,166) HDRY,HWET,WATL,WATH,CR
      KCK=1
      HROOT=G(2)
      RUNOF=0.0
      CUMS=0.0
      CUMB=0.0
      CUMM=0.0
      SUMA=0.0
      CALL PLOT (KK,WATH,W,DD,SMAX,SO)
      WRITE(6,166) TIME
C***********************************************************************
C----COMPUTATION OF CONDUCTIVITY (B) AND WATER CAPACITY (C)
16    TOP=WATH
      BOT=WATL
      HKP=H(1)
      WKP=W(1)
      IF (FOR-0.0) 17,19,18
17    W(1)=WATL
      H(1)=HDRY
      GO TO 19
18    W(1)=WATH
      H(1)=HWET
19    TWW=(W(1)+Y(1))*0.5
      J=(TWW-T(1))/DELW+1.0
      BB=(TWW-T(J))/DELW
      DIFFA=(D(J+1)-D(J))*BB+D(J)
      HI=(P(J+1)-P(J))*BB+P(J)
      DO 37 I=1,K
      TW=(W(I+1)+Y(I+1))*0.5
      J=(TW -T(1))/DELW+1.0
      BB=(TW-T(J))/DELW
      DIFFB=(D(J+1)-D(J))*BB+D(J)
      GI=(P(J+1)-P(J))*BB+P(J)
219   IF(HI-GI)20,32,20
20    B(I)=(DIFFA-DIFFB)/(HI-GI)
      IF (I-1) 21,21,33
21    IF (EOR-0.0) 22,33,22
22    ER=(B(1)*(H(1)*TT-H(2)*TT-G(2)*TM+G(1)*TM+DD(2)))/DD(2)
      IF (ABS(1.1*EOR-ER)-ABS(0.1*EOR)) 236,236,23
23    IF(KCK.EQ.1) GO TO 220
      IF (KCK-20)305,236,236
236   H(1)=(1.1*EOR*DD(2)/B(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
      IF(H(1).LT.HDRY) H(1)=HDRY
      IF (H(1).GT.HWET) H(1)=HWET
      GO TO 33
220   H(1)=HKP
      W(1)=WKP
      KCK=KCK+1
      GO TO 19
305   KCK=KCK+1
      IF (ER-EOR) 24,33,26
24    IF (W(1)-WATH) 25,33,33
25    BOT=W(1)
      W(1)=(W(1)+TOP)*0.5
      GO TO 28
26    IF (W(1)-WATL) 33,33,27
27    TOP=W(1)
      W(1)=(W(1)+BOT)*0.5
28    J=(W(1)-T(1))/DELW+1.0
      BB=(W(1)-T(J))/DELW
      IF(EOR-0.0)30,33,30
30    H(1)=(P(J+1)-P(J))*BB+P(J)
218   TWW=(W(1)+Y(1))*0.5
```

```
      J=(TWW-T(1))/DELW+1.0
      RR=(TWW-T(J))/DELW
      DIFFA=(D(J+1)-D(J))*RR+D(J)                                       A 110
      HI=(P(J+1)-P(J))*RR+P(J)                                          A 111
      GO TO 219                                                         A 112
 32   B(I)=(D(J+1)-D(J))/(P(J+1)-P(J))
      IF (I-1) 33,21,33                                                 A 142
 33   TWW=TW                                                            A 143
      HI=GI                                                             A 144
      DIFFA=DIFFB                                                       A 145
      TW=(W(I+1)+Y(I+1))*0.5                                            A 146
      J=(TW -T(1))/DELW+1.0                                             A 147
 35   C(I+1)=DELW/(P(J+1)-P(J))
 37   CONTINUE                                                          A 151
      KCK=1                                                             A 154
      IF(FOR.GT.0.0.AND.ET.GE.0.0) GO TO 6666
      IF(FOR.GT.0.0.AND.ET.LT.0.0) GO TO 5555
 6666 ETPL=ET-FOR
      IF(ET.GE.0.0) GO TO 39
      IF(ETPL-0.0) 365,39,39
 5555 ETPL=ET
C************************************************************************
C     SEARCHING FOR THE PROPER HROOT VALUE
 365  HHOLD=HROOT
      HROOT=HLOW
      SINK=0.0                                                        BR
      DO 250 I=2,K
  250 E(I)=G(I)-0.5715*SF(I)-DD(I)*PRES
      DO 420 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 420
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 420  CONTINUE
      IF(SINK-ETPL.GT.0.0) GO TO 402
      HROOT=HHOLD
 410  HROOT=1.2*HROOT
      SINK=0.0
      DO 421 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 421
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 421  CONTINUE
      IF(SINK-ETPL)411,402,410
 411  HRLO=HROOT
      HROOT=HHOLD
      LCOUNT=0
 412  HROOT=0.8*HROOT
      LCOUNT=LCOUNT+1
      IF(LCOUNT.EQ.5) GO TO 490
      SINK=0.0
      DO 422 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 422
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 422  CONTINUE
      IF(SINK-ETPL)412,402,413
 413  HRHI=HROOT
      GO TO 491
  490 HRHI=HHI
 491  LCOUNT=0
      HROOT=HHOLD
 405  SINK=0.0
      DO 400 I=2,K                                                      BR
      IF(HROOT-E(I).GT.0.0) GO TO 400                                   BR
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 400  CONTINUE
      LCOUNT=LCOUNT+1                                                   BR
      IF(LCOUNT.EQ.20) GO TO 402                                        BR
      IF(ABS(SINK-ETPL)-0.002)402,402,401
 401  IF(SINK-ETPL)403,402,404
                                                                        BR
```

```
403   HRLO=HROOT                                                        BB
      HROOT=0.5*(HROOT+HRHI)                                            BB
      GO TO 405                                                         BB
404   HRHI=HROOT
      HROOT=0.5*(HROOT+HRLO)                                            BB
      GO TO 405                                                         BB
   39 DO 251 I=2,K
      SINK=0.0
  251 A(I)=0.0
      GO TO 38
C     A IS THE DEL WATER/DELT CAUSED BY PLANT EXTRACTION
  402 DO 406 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 407
      A(I)=B(I)*(HROOT-E(I))*2.0*RDF(I)/(DD(I+1)-DD(I-1))
      GO TO 406
407   A(I)=0.0
406   CONTINUE
C*******************************************************************
C-----COMPUTATION OF TRIDIAGONAL MATRIX MAIN BODY                   A 158
38    DO 42 I=2,K                                                  A 159
      POT=(DD(I+1)-DD(I-1))/(2.0*DELT)                             A 160
      DLXA=(DD(I)-DD(I-1))                                         A 161
      DLXB=(DD(I+1)-DD(I))                                         A 162
      BB=C(I)*POT/TT+B(I)/DLXB+B(I-1)/DLXA                         A 1621
      DA=(C(I)*POT*G(I)+(B(I)/DLXB)*(TM*(G(I+1)-G(I))-DLXB)+(B(I-1)/DLXA  A 1622
     1)*(TM*(G(I-1)-G(I))+DLXA)+A(I)*(DD(I+1)-DD(I-1))*0.5)/TT
      IF(I-2)390,390,40
  390 IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 394
      DA=DA-((B(I-1)/DLXA)*(TM*(G(I-1)-G(I))+DLXA))/TT+FOR/TT
      BB=BB-B(I-1)/DLXA
      GO TO 393
  394 DA=DA+H(I-1)*B(I-1)/DLXA
  393 F(I)=DA/BB
      E(I)=(B(I)/DLXB)/BB                                          A 1661
      GO TO 42                                                     A 167
40    IF (I-K) 41,43,43                                            A 168
41    E(I)=(B(I)/DLXB)/(BB-(B(I-1)/DLXA)*E(I-1))                   A 169
      F(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))     A 170
   42 CONTINUE
43    BB=BB-TAA*B(I)/DLXB                                          A 172
      DA=DA+TAA*(B(I)/DLXB)*((G(I)-G(I+1))*TM+DLXB)/TT+TPH*B(I)/DLXB*H(  A 173
     1KK)                                                          A 174
      H(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))     A 1741
44    I=I-1                                                        A 175
      H(I)=E(I)*H(I+1)+F(I)                                        A 176
      IF (I-2) 45,45,44                                            A 177
45    IF(TAA-1.0)47,46,46
46    H(KK)=H(K)+DD(KK)-DD(K)                                      A 178
47    DO 60 I=2,KK
300   IF (H(I)-HWET-DD(I)) 60,60,55
55    H(I)=HWET+DD(I)
60    CONTINUE                                                     A 197
C*******************************************************************
C-----COMPUTATION OF WATER CONTENTS AS A FUNCTION OF PRESSURES JUST COMP  A 199
      IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 1005
      WFDD=FOR
      H(1)=(FOR*DD(2)/B(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
      GO TO 134
 1005 WFDD=B(1)*((H(1)-H(2))*TT+(G(1)-G(2))*TM+DD(2))/DD(2)        A 189
 134  I=1
 62   IF (H(I)-G(I)) 65,116,65
65    NHI=50                                                       A 206
      NLO=1                                                        A 207
      J=25                                                         A 208
66    IF (H(I)-P(J)) 67,72,68                                      A 209
67    NHI=J                                                        A 210
      GO TO 69                                                     A 211
68    NLO=J                                                        A 212
69    JT=J                                                         A 213
```

```
      J=(NHI-NLO)/2+NLO                                                 A 214
      IF (J-JT) 66,70,66                                                A 215
70    IF (H(I)-P(J)) 71,72,72                                           A 216
71    J=J-1                                                             A 217
72    WAT=(H(I)-P(J))*DELW/(P(J+1)-P(J))+T(J)                           A 218
      W(I)=WAT
      GO TO 117
116   W(I)=Y(I)                                                         A 310
  117 DO 268 I=2,KK
268   W(I)=C(I)*(H(I)-G(I))+Y(I)
      GO TO 269
269   SUM3=0.0
      SUM2=0.0                                                          A 326
      SUM1=0.0
      DO 131 I=2,K                                                      A 327
      SUM1=W(I)+SUM1                                                    A 328
      SUM2=Y(I)+SUM2                                                    A 329
      IF (ABS(SUM1-SUM2)-ABS(SUM3)) 131,131,130                         A 330
130   SUM3=SUM1-SUM2                                                    A 331
131   CONTINUE                                                          A 332
      IF(ABS(SUM3)-ABS(CONV))63,63,132
  132 IF(DELT-DETT*0.1)63,63,133
  133 DELT=0.5*DELT
      GO TO 38                                                          A 336
   63 SUM1=0.0
      SUM2=0.0
      DO 800 I=2,K
      SUM1=W(I)*(DD(I+1)-DD(I-1))/2.+SUM1
  800 SUM2=Y(I)*(DD(I+1)-DD(I-1))/2.+SUM2
      CWF=SUM1-PIT
      WFRDD=(SUM1-SUM2)/DELT
      WFUU=B(NB)*((H(NB)-H(NB+1))*TT+(G(NB)-G(NB+1))*TM+DD(NB+1)-DD(NB))
     1/(DD(NB+1)-DD(NB))
      CUMS=WFDD*DELT+CUMS                                               A 341
      CUMB=WFUU*DELT+CUMB
      SUMA=SUMA+SINK*DELT
      CWFLX=(SUM1-SUM2)                                               A 343A
C*********************************************************************
      KB=K-1
      DO 999 I=1,KB
      DELX=(DD(I+2)-DD(I))/2.0
      WFRU=(B(I)*((H(I)-H(I+1))*TT+(G(I)-G(I+1))*TM+DD(I+1)-DD(I))*DELT)  A 344
     1/(DD(I+1)-DD(I))
      WFRD=(B(I+1)*((H(I+1)-H(I+2))*TT+(G(I+1)-G(I+2))*TM+DD(I+2)-DD(I+1  A 3451
     1))*DELT)/(DD(I+2)-DD(I+1))
      WFRU=WFRU/DELX
      WFRD=WFRD/DELX
      A(I+1)=A(I+1)*DELT
      IF(ABS(WFRU-WFRD).LT.0.0001)GO TO 200
      IF(I.EQ.1)GO TO 201
      IF(WFRU.GE.0.0.AND.WFRD.GE.0.0)GO TO 205
      IF(WFRU.LE.0.0.AND.WFRD.LE.0.0)GO TO 209
      IF(WFRU.GE.0.0.AND.WFRD.LE.0.0)GO TO 208
      IF(WFRU.LE.0.0.AND.WFRD.GE.0.0)GO TO 210
  205 SE(I+1)=(SS(I+1)*Y(I+1)+SS(I)*WFRU-SS(I+1)*WFRD)/W(I+1)
      GO TO 200
  201 IF(EOR-0.0)203,204,202
 203  IF(WFRD.GT.0.0)GO TO 206
 207  SE(2)=(SS(2)*Y(2)-SS(3)*WFRD)/W(2)
      GO TO 200
  206 SE(2)=(SS(2)*Y(2)-SS(2)*WFRD)/W(2)
      GO TO 200
  204 IF(WFRD.LT.0.0)GO TO 207
      GO TO 206
  202 IF(WFRD.GT.0.0)GO TO 205
  208 SE(I+1)=(SS(I+1)*Y(I+1)+SS(I)*WFRU-SS(I+2)*WFRD)/W(I+1)
      GO TO 200
  209 SE(I+1)=(SS(I+1)*Y(I+1)+SS(I+1)*WFRU-SS(I+2)*WFRD)/W(I+1)
      GO TO 200
  210 SE(I+1)=(SS(I+1)*Y(I+1)+SS(I+1)*WFRU-SS(I+1)*WFRD)/W(I+1)
 200 IF(SE(I+1).LT.0.0) SE(I+1)=SS(I+1)
 999  CONTINUE
      DO 704 I=1,KK
704   SD(I)=SE(I)*W(I)
705   IF(EOR-0.0)136,136,135
135   RUNOF=(EOR-WFDD)*DELT+RUNOF
136   TIME=TIME+DELT
      IF (LL-MM) 138,137,137
 137 CALL PLOT (KK,WATH,W,DD,SMAX,SD)
      WRITE (6,166) (H(I),I=1,KK)
      WRITE(6,166)(SE(I),I=1,KK)
      WRITE(6,166)(A(I),I=2,K)
      LL=0
      WRITE (6,184)
 138  WRITE (6,166) TIME,CWF,EOR,WFDD,HROOT,CUMS,CUMP,SUMA,WFRDD,WFUU,SE
     1(K)
      IF (SUM3-0.0) 139,301,139
 301 DELT=2.0*DELT
      GO TO 145
139   TW=ABS(COND*DELT/SUM3)
140   IF (TW-0.1*DETT) 141,142,142
 141 TW=0.1*DETT
      GO TO 144
 142 IF(TW-1000.0*DETT)144,144,143
 143  TW=1000.0*DETT
 144 IF(TW.GT.2.0*DELT) GO TO 301
      DELT=TW
C*********************************************************************
C-----TEST TO SEE IF EVAP OR RAIN INTENSITY (EOR) HAS CHANGED
145   IF(TIME-V(KC+1))148,147,148
147   CALL PLOT (KK,WATH,W,DD,SMAX,SD)
      WRITE (6,166) (H(I),I=1,KK)
      WRITE(6,166)(SE(I),I=1,KK)
      WRITE(6,166)(A(I),I=2,KK)
      WRITE(6,184)
      WRITE (6,166) TIME,CWF,EOR,WFDD,HROOT,CUMS,CUMP,SUMA,WFRDD,WFUU,SE
     1(K)
      DELT=DETT
      EOR=V(KC+2)
      SE(1)=SF(KC+2)
      ET=TET(KC+2)
      KC=KC+2
      GO TO 151
148   IF(TIME+DELT-V(KC+1))151,151,149
149   DELT=V(KC+1)-TIME
151   LL=LL+1
      IF (TIME-CUMT) 153,152,152
152   IF (ML-LMM) 162,162,1
153   Y(1)=(W(1)+Y(1))*0.5
      J=(Y(1)-T(1))/DELW+1.0
      BB=(Y(1)-T(J))/DELW
      IF (EOR-0.0) 155,156,155
155   G(1)=(P(J+1)-P(J))*BB+P(J)
156   DO 161 I=2,KK
      J=(W(I)-T(1))/DELW+1.0
      BB=(W(I)-T(J))/DELW
      G(I)=(P(J+1)-P(J))*BB+P(J)
      TW=(W(I)-Y(I))+W(I)
      IF (TW-WATH) 157,157,159
157   IF (TW-WATL) 158,160,160
158   TW=WATL
      GO TO 160
159   TW=WATH
160   Y(I)=W(I)
      W(I)=TW
      SS(I)=SE(I)
161   CONTINUE
      SS(1)=SE(1)
      GO TO 16
162   STOP
```

```
C*******************************************************************************
167   FORMAT (20I3)
165   FORMAT (7F10.4)
166   FORMAT (11F11.4)
169   FORMAT (14H  K   MM IFP NH)
170   FORMAT (119H    WATER     POTENTIAL    CONDUCTIVITY DIFFUSIVITY
     1C(I)     DEPTH        W-DEPTH      H-DEPTH      PDF-DEPTH    SE-DEPTH)
172   FORMAT (53H    HDRY          HWET          WATL          WATH        C9)
179   FORMAT (54H  TIME END    SOIL FLUX    ET FLUX      SALT CONC.      )
180   FORMAT (66H  DELX          DETT          GRAVY          COND        TELW
     1          TIME)
181   FORMAT (66H    TT            CUMT          TAA           HLOW        HHT
     1          PRES)
  134 FORMAT(1H ,'   TIME          CWF           FOR           WFDD        HROOT
     1    CUMS          CUMA          TRANS.       WFROD         WFUU        SEEKI')
      END




      SUBROUTINE PLOT(N,WMAX,WVALUE,XVALUE,TMAX,TVALUE)
      DIMENSION ALINE(101),WVALUE(25),XVALUE(25),TVALUE(25)
      DATA FILL,AXIS,CHAR,CHAN,SAME/1H ,1H.,1HW,1HS,1H*/
      WRITE (6,7) WMAX,TMAX
      DO 1 J=1,101
1     ALINE(J)=AXIS
      WRITE (6,8) (ALINE(K),K=1,101)
      DO 2 J=1,101
2     ALINE(J)=FILL
      ALINE(1)=AXIS
      DO 4 L=1,N
      J=100.0*(WVALUE(L)/WMAX)+1.5
      JJ=100.0*(TVALUE(L)/TMAX)+1.5
      IF(J.LT.1) J=1
      IF(J.GT.101) J=101
      IF(JJ.LT.1) JJ=1
      IF(JJ.GT.101) JJ=101
      IF (J-JJ)10,11,10
11    ALINE (J)=SAME
      GO TO 12
10    ALINE (J)=CHAR
      ALINE(JJ)=CHAN
12    WRITE(6,9) XVALUE(L),WVALUE(L),TVALUE(L),(ALINE(K),K=1,101)
      ALINE(JJ)=FILL
      ALINE(J)=FILL
   55 ALINE(1)=AXIS
4     CONTINUE
      DO 5 J=1,101
5     ALINE(J)=AXIS
      WRITE (6,8) (ALINE(K),K=1,101)
      RETURN
    7 FORMAT (24H  X VALUE WVALUE  SVALUE,5X,17H  MAX WAT CONT IS,F7.4,'
     1  MAX SALT CONCENTRATION IS',F6.2,1H )
8     FORMAT (31X,101A1)
    9 FORMAT(1H ,F6.1,F9.4,F8.2,7H        ,101A1)
      END
```

## FORTRAN Listing Combined Water and Salt Models

```
C     PROGRAM-SOIL WATER.SALT.FLOW WITH PLANT UPTAKE
C     PROGRAM OF SEP. 25.1971
C     HWET IS PRESSURE OF HIGHEST POSSIBLE WATER CONTENT
C     V IS BOUNDARY CONDITIONS AT TOP AND TIMES CONDITIONS APPLY
C     DETT IS TIME INCREMENT TO START WITH AND LOWEST TO USE
C     CONO IS SMALLEST WATERCONTENT CHANGE ALLOWED EACH COMPUTATION
C     GRAVY IS GRAVITY COMPONENT USUALLY THE SAME AS DELX
C     DELW IS WATER CONTENT DIFFERENCE CORRESPONDING TO TABLE INCREMENTS
C     T IS WATER CONTENT TABLE  HAS EQUAL SPACED INCREMENTS
C     TIME IS CUMULATIVE TIME AT START OF COMPUTATION
C     TT IS 1.0 FOR LAASONEN AND 0.5 FOR CRANK NICHOLSON
C     CUMT IS TIME AT END OF COMPUTATION
C     TAA=1. FOR ZERO FLUX AT BOTTOM.TAA=0 FOR H(KK) CONSTANT               A
C       FROM G(I) OR H(I)=G(I)
C     CTM IS LOWEST VALUE OF DELT PERMITTED--IF AS LOW STOPS
C     HDRY IS PRESSURE OF LOWEST POSSIBLE WATER CONTENT
C     PP IS PRESSURE TABLE(WETTING)STARTING WITH LOWEST PRESSURE
C     D IS CONDUCTIVITY TABLE STARTING WITH LOWEST WATER CONTENT VALUE
C     DD SAME AS ABOVE EXCEPT STARTS FROM WETTING
C     C IS WATER CAPACITY AS A FUNCTION OF DEPTH  BEGINNING AT TOP
C     DELX IS DEPTH INCREMENT
C     W IS WATER CONTENT  AS A FUNCTION OF DEPTH  BEGINNING AT TOP
C     H IS WATER PRESSURE AS A FUNCTION OF DEPTH  BEGINNING AT TOP
C     WATL IS LOWEST POSSIBLE WATER CONTENT
C     WATH IS HIGHEST POSSIBLE WATER CONTENT
C     CR IS A CONSTANT TO MULTIPLY D ARRAY BY--USUALLY 1.0
C     K IS NO. OF DELX INCREMENTS.MM NO. OF TIMES H.W PRINTED.KIT NO.OF     A  12
C     K IS NO. OF DELX INCREMENTS.MM NO. OF TIMES H.W PRINTED.KIT NO.OF     A  13
C----START HERE FOR A NEW PROGRAM
C     MI IS TO PRINT H.W ARRAYS EACH ITER..IER NO. OF V ELEMENTS            A  14
C     HROOT IS THE ACTUAL ROOT WATER POTENTIAL
C     BB REPRESENTS PLANT UPTAKE ADDITIONS
C     HLOW IS THE MINIMUM ROOT POTENTIAL ALLOWED
C     HHI IS THE MAXIMIM  ROOT POTENTIAL ALLOWED
C     ET IS THE POTENTIAL EVAPOTRANSPIRATION.ALWAYS NEGATIVE
C     WFOO IS THE WATER FLOW RATE AT THE SURFACE
C     ETPL IS THE POTENTIAL TRANSPIRATION.ALWAYS NEGATIVE
C     SUMS--SALT CONCENTRATION GOING OUT
C     TET IS THE BOUNDARY POTENTIAL ET.ALWAYS NEGATIVE.LTV ARRAY
C     DD.H.G.Y.W.RDF.A.SE.SS.SD ARRAYS ARE OF SAME DIMENSION AT LEAST =KK
C     P.D.T.ARE OF EQUAL DIMENSIONS.ARE EQUAL TO 60 AT MOST
C     SF.TET.V ARRAYS ARE OF SAME DIMENSION AT LEAST =IER
C     CS=CALCIUM.MS=MAGNESIUM.SN=SODIUM.CL=CHLORIDE.SU=SULPHATE.HC=BICARBONATE
C     CE.ME.EN.ARE EXCHANGBLE CALCIUM.MAGNESIUM.SODIUM
C     CAL.CAS.ARE CALCITE.
C     CAL.CAS.ARE CALCITE AND GYPSUM.CSO.MGSO.ARE ION PAIRS
C     CSG.MSO.SNO.CLO.HCO.SUO.CSX.MGSX.ARE OLD CONCENTRATIOS
C     AM.AC.SAM.SAC.ARE TABLES OF IONIC-STRENGTH ACTIVITY COEFFICIENT OF
C     CALCIUM AND SODIUM IONS
C     TCA.TMG.ARE TOTALCONCERATIONS(CATIONS+ION-PAIRS)
      DIMENSION CF(35).MF(35).SNF(35).SUF(35).CSOF(35).MGSF(35).CLF(35)
      DIMENSION HCF(35)
      DIMENSION DD(25).H(25).G(25).Y(25).W(25).RDF(25).A(25).SE(25)
      DIMENSION SS(25).SD(25).C(25).B(25).E(25).F(25)
      DIMENSION SF(65).TET(65).V(65)
      DIMENSION P(50).D(50).T(50)
      DIMENSION CS(27).MS(27).SN(27).SU(27).CL(27).HC(27).CE(26).ME(26)
      DIMENSION EN(26).CAS(27).CSO(27).MGSX(27).TMG(27)
      DIMENSION CSG(27).MSO(27).SNO(27).CLO(27).HCO(27).SUO(27).CSX(27)
      DIMENSION AM(27).AC(27).SAM(26).SAC(26)
      DIMENSION TCA(26)
      DIMENSION CAL(27).MGSO(27)
      REAL MF.MGSF
      REAL MGSO.MGSX.MSP
      REAL MSO
      REAL MS,ME,MFA,MSA
      WRITE(6,8765)
 8765 FORMAT(1H1,25X,'**************************************************
     *************')
      WRITE(6,8766)
 8766 FORMAT(1H ,34X,'CROP ALFALFA..ROOT DEPTH IS (2) FEET.')
      WRITE(6,9999)
 9999 FORMAT(1H ,25X,'DATA ARE FROM 3/8/1971 TO11/9/1971 CROP ALFALFA. F
     1=0.10FT')
      WRITE(6,8767)
 8767 FORMAT(1H ,25X,'**************************************************
     *************')
      READ 163, ML
      LMM=0                                                           ▲   9
1     LMM=LMM+1                                                       ▲  11
      READ 163, K,MM,IER,NR,ND                                        ▲  10
      KK=K+1
      READ 165,(DD(I),I=1,KK)                                         ▲  18
      READ(5,165) (TET(I),I=1,IER)
      READ(5,165) (RDF(I),I=1,KK)
      KC=1
      ET=TET(1)
      LL=MM
      READ(5,165)(P(I),I=1,ND)                                        ▲  19
      READ(5,165)(D(I),I=1,ND)
      READ 165, (W(I),I=1,KK)
      READ 165, (V(I),I=1,IER)                                        ▲  25
      READ 165, DELX,DETT,CRAVY,CONO,DELW,TIME                        ▲  26
      READ 165, TT,CUMT,TAA,HLOW,HHI,RRES
      READ 165, HDRY,HWET,WATL,WATH,CB
C     BOUNDRY CONDITIONS FOR SALT FLOW
      READ 165,(SF(I),I=1,IER)
      READ(5,165)(CF(I),I=1,IER)
      READ(5,165)(MF(I),I=1,IER)
      READ(5,165)(SNF(I),I=1,IER)
      READ(5,165)(SUF(I),I=1,IER)
      READ(5,165)(CLF(I),I=1,IER)
      READ(5,165)(HCF(I),I=1,IER)
      READ(5,165)(CSOF(I),I=1,IER)
      READ(5,165)(MGSF(I),I=1,IER)
      WRITE(6,166)(CF(I),I=1,IER)
      WRITE(6,166)(MF(I),I=1,IER)
      WRITE(6,166)(SNF(I),I=1,IER)
      WRITE(6,166)(SUF(I),I=1,IER)
      WRITE(6,166)(CLF(I),I=1,IER)
      WRITE(6,166)(HCF(I),I=1,IER)
      WRITE(6,166)(CSOF(I),I=1,IER)
      WRITE(6,166)(MGSF(I),I=1,IER)
      READ(5,165)AM
      READ(5,165)AC
      READ(5,165)SAM
      READ(5,165)SAC
      WRITE(6,166)(AM(I),AC(I),I=1,27)
      WRITE(6,166)(SAM(I),SAC(I),I=1,26)
C     INITAL CONDITIONS FOR SALT FLOW
      READ(5,165)(CS(I),I=1,KK)
      READ(5,165)(MS(I),I=1,KK)
      READ(5,165)(SN(I),I=1,KK)
      READ(5,165)(SU(I),I=1,KK)
      READ(5,165)(CL(I),I=1,KK)
      READ(5,165)(HC(I),I=1,KK)
      READ(5,165)(CAL(I),I=1,KK)
      READ(5,165)(CAS(I),I=1,KK)
      WRITE(6,166)(CS(I),I=1,KK)
      WRITE(6,166)(MS(I),I=1,KK)
      WRITE(6,166)(SN(I),I=1,KK)
      WRITE(6,166)(SU(I),I=1,KK)
      WRITE(6,166)(CL(I),I=1,KK)
      WRITE(6,166)(HC(I),I=1,KK)
      WRITE(6,166)(CAL(I),I=1,KK)
      WRITE(6.166)(CAS(I).I=1.KK)
      WRITE (6.169)
      WRITE (6.163) K.MM.IER.NR.ND
      SMAX=WATH•400.
      P(1)=P(1)•1.0E•03                                               A   38
      T(1)=0.0
      STIM=0.0
      DO 900 I=2.ND
      T(I)=DELW•T(I-1)
  900 P(I)=P(I)•1.0E•03
C-----------------------------------------------------------------
      DO 600 I=2.KK
      CSA=CS(I)
      MSA=MS(I)
      SNA=SN(I)
      SUA=SU(I)
      CLA=CL(I)
      HCA=HC(I)
      SEA=CS(I)•MS(I)•SN(I)
      CALL EQEXCH(CSA.MSA.SNA.CLA.SUA.HCA.CEA.MEA.ENA.CSP.MSP.SEA.AM.AC.
     QSAM.SAC)
      CS(I)=CSA
      MS(I)=MSA
      SN(I)=SNA
      SU(I)=SUA
      CL(I)=CLA
      HC(I)=HCA
      CE(I)=CEA
      ME(I)=MEA
      EN(I)=ENA
      CSO(I)=CSP
      MGSO(I)=MSP
      SE(I)=SEA
      WRITE(6.166)CS(I).MS(I).SN(I).CL(I).SU(I).HC(I).CE(I).ME(I).EN(I).
     GCSO(I).MGSO(I)
  600 CONTINUE
      CS(2)=2590.9588
      CL(2)=2590.9588
  825 WRITE(6.911)
      DO 910 I=1.KK
  910 WRITE(6.166)(CS(I).MS(I).SN(I).SU(I).CL(I).HC(I).CE(I).ME(I).EN(I)
     1.CAS(I).CSO(I))
      WRITE(6.166)MGSO
C-----------------------------------------------------------------
      SE(1)=SF(1)
      CS(1)=CF(1)
      MS(1)=MF(1)
      SN(1)=SNF(1)
      SU(1)=SUF(1)
      CL(1)=CLF(1)
      HC(1)=HCF(1)
      CSO(1)=CSOF(1)
      MGSO(1)=MGSF(1)
      CWFLX=0.0                                                       A   74
      COR=V(1)
      DELT=DETT                                                       A   76
      TM=1.0-TT                                                       A   77
      TBB=1.0-TAA                                                     A   82
      YMAX=WATH
      DO 14 I=1.KK
      SS(I)=SE(I)
      SD(I)=SE(I)•W(I)                                                A   87
   14 Y(I)=W(I)                                                       A   89
      PIT=0.0
      DO 15 I=2.K
   15 PIT=W(I)•(DD(I•1)-DD(I-1))/2.•PIT
      WRITE (6.170)
      TW=D(1)                                                         A   39
      D(1)=(D(1)•(P(2)-P(1)))•CB
      J=(W(1)-T(1))/DELW•1.0
      H(1)=(P(J+1)-P(J))*(W(1)-T(J))/DFLW+P(J)
      G(1)=H(1)
      C(1)=DELW/(P(J+1)-P(J))
      WRITE ( 6,166) T(1),P(1),TW,D(1),C(1),DD(1),W(1),H(1),ROF(1),SF(1)
      DO 3 I=2,KK
      TW=D(I)
      D'I)=D(I)+(P(I)-P(I-1))*CA+D(I-1)
      J=(W(I)-T(1))/DELW+1.0                                              A   41
      H(I)=(P(J+1)-P(J))*(W(I)-T(J))/DFLW+P(J)
      C(I)=DELW/(P(J+1)-P(J))
      G(I)=H(I)
      WRITE ( 6,166) T(I),P(I),TW,D(I),C(I),DD(I),W(I),H(I),ROF(I),SF(I)  A   86
3     CONTINUE
      N=KK+1
      DO 2 I=N,ND
      TW=D(I)
      D(I)=D(I)+(P(I)-P(I-1))*CB+D(I-1)
C     -----------------------------------------------------------------
2     WRITE (6,166) T(I),P(I),TW,D(I)
C     D IS NOW DIFFUSIVITY TIMES DELW NOT CONDUCTIVITY
      WRITE (6,179)
      DO 5 I=2,IER,2
5     WRITE (6,165) V(I),V(I-1),TET(I-1),SF(I-1)
      WRITE (6,180)
      WRITE (6,166) DELX,DETT,GRAVY,CONO,DELW,TIME
      WRITE (6,181)
      WRITE (6,166) TT,CUMT,TAA,HLOW,HHI,RRES
      WRITE (6,172)
      WRITE (6,166) HDRY,HWET,WATL,WATH,CB
C     -----------------------------------------------------------------
      KCK=1
      HROOT=G(2)                                                          A   93
      RUNOF=0.0
      CUMS=0.0                                                            A   95
      CUMB=0.0                                                            A   96
      CUMM=0.0                                                            A   97
      SUMA=0.0                                                            A   98
      CALL PLOT (KK,WATH,W,DD,SMAX,SD)
      WRITE(6,166) TIME
C----COMPUTATION OF CONDUCTIVITY (B) AND WATER CAPACITY (C)
16    TOP=WATH                                                            A   99
      BOT=VATL                                                            A  100
      HKP=H(1)                                                            A  101
      WKP=W(1)
      IF (EOR-0.0) 17,19,18
17    W(1)=WATL                                                           A  102
      H(1)=HDRY                                                           A  103
      GO TO 19                                                            A  104
18    W(1)=WATH                                                           A  105
      H(1)=HWET                                                           A  106
19    TWW=(W(1)+Y(1))*0.5                                                 A  107
      J=(TWW-T(1))/DFLW+1.0                                               A  108
      BB=(TWW-T(J))/DELW
      DIFFA=(D(J+1)-D(J))*BB+D(J)                                         A  110
      HI=(P(J+1)-P(J))*BB+P(J)                                            A  111
      DO 37 I=1,K                                                         A  112
      TW=(W(I+1)+Y(I+1))*0.5                                              A  113
      J=(TW -T(1))/DELW+1.0                                               A  114
      BB=(TW-T(J))/DELW
      DIFFB=(D(J+1)-G(J))*BB+D(J)                                         A  116
      GI=(P(J+1)-P(J))*BB+P(J)                                            A  117
219   IF(HI-GI)20,32,20
20    B(1)=(DIFFA-DIFFB)/(HI-GI)
      IF (I-1) 21,21,33                                                   A  120
21    IF (EOR-0.0) 22,33,22                                               A  121
22    ER=(B(1)*(H(1)*TT-H(2)*TT-G(2)*TM+G(1)*TM+DD(2)))/DD(2)
      IF (ABS(1.1*FOR-ER)-ABS(0.1*EOR)) 236,236,23
23    IF(KCK.EQ.1) GO TO 220
      IF(KCK-10) 305,236,236
236   H(1)=(EOR*DD(2)/B(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
```

```
      IF(H(1).LT.HDRY) H(1)=HDRY
      IF (H(1).GT.HWET) H(1)=HWET
      GO TO 33
220   H(1)=HKP
      W(1)=WKP
      KCK=KCK+1
      GO TO 19
305   KCK=KCK+1
      IF (ER-EOR) 24,33,26
24    IF (W(1)-WATH) 25,33,33                                        A 1 26
25    BOT=W(1)                                                       A 1 27
      W(1)=(W(1)+TOP)*0.5                                            A 1 28
      GO TO 28                                                       A 1 29
26    IF (W(1)-WATL) 33,33,27                                        A 1 30
27    TOP=W(1)                                                       A 1 31
      W(1)=(W(1)+BOT)*0.5                                            A 1 32
   28 J=(W(1)-T(1))/DELW+1.0
      BB=(W(1)-T(J))/DELW                                            A 1 34
      IF(EOR-0.0) 30,33,30
30    H(1)=(P(J+1)-P(J))*BB+P(J)                                     A 1 35
  218 TWW=(W(1)+Y(1))*0.5
      J=(TWW-T(1))/DELW+1.0
      BB=(TWW-T(J))/DELW                                             A 1 10
      DIFFA=(D(J+1)-D(J))*BB+D(J)                                    A 1 11
      HI=(P(J+1)-P(J))*BB+P(J)                                       A 1 12
      GO TO 219
32    B(I)=(D(J+1)-D(J))/(P(J+1)-P(J))                               A 1 42
      IF (I-1) 33,21,33                                              A 1 43
33    TWW=TW                                                         A 1 44
      HI=GI                                                          A 1 45
      DIFFA=DIFFB                                                    A 1 46
      TW=(W(I+1)+Y(I+1))*0.5                                         A 1 47
      J=(TW -T(1))/DELW+1.0
35    C(I+1)=DELW/(P(J+1)-P(J))                                      A 1 51
37    CONTINUE                                                       A 1 54
      KCK=1
      IF(EOR.GT.0.0.AND.ET.GE.0.0) GO TO 6666
      IF(EOR.GT.0.0.AND.ET.LT.0.0) GO TO 5555
 6666 ETPL=ET-EOR
      IF(ET.GE.0.0) GO TO 39
      IF(ETPL-0.0) 365,39,39
 5555 ETPL=ET
365   HHOLD=HROOT                                                  BB
      HROOT=HLOW
      SINK=0.0
      DO 250 I=2,K
  250 E(I)=G(I)-0.5715*SE(I)-DD(I)*RRES
      DO 420 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 420
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 420  CONTINUE
      IF(SINK-ETPL.GT.0.0) GO TO 402
      HROOT=HHOLD
410   HROOT=1.2*HROOT
      SINK=0.0
      DO 421 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 421
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 421  CONTINUE
      IF(SINK-ETPL)411,402,410
 411  HRLO=HROOT
      HROOT=HHOLD
      LCOUNT=0
412   HROOT=0.8*HROOT
      LCOUNT=LCOUNT+1
      IF(LCOUNT.EQ.5) GO TO 490
      SINK=0.0
      DO 422 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 422
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
  422  CONTINUE
       IF(SINK-ETPL)412,402,413
  413  HRHI=HROOT
       GO TO 491
  490  HRHI=HHI
  491  LCOUNT=0
       HROOT=HHOLD
  405  SINK=0.0
       DO 400 I=2,K                                                      BB
       IF(HROOT-E(I).GT.0.0) GO TO 400                                   BB
       SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
  400  CONTINUE
       LCOUNT=LCOUNT+1                                                   BB
       IF(LCOUNT.EQ.20) GO TO 402                                        BB
       IF(ABS(SINK-ETPL)-0.002)402,402,401
  401  IF(SINK-ETPL)403,402,404
  403  HRLO=HROOT                                                        BB
       HROOT=0.5*(HROOT+HRHI)                                            BB
       GO TO 405                                                         BB
  404  HRHI=HROOT                                                        BB
       HROOT=0.5*(HROOT+HRLO)
       GO TO 405                                                         BB
   39  DO 251 I=2,K                                                      BB
       SINK=0.0
  251  A(I)=0.0
       GO TO 38
C      ------------------------------------------------------------------
C      A IS THE DEL WATER/DELT CAUSED BY PLANT EXTRACTION
  402  DO 406 I=2,K
       IF(HROOT-E(I).GT.0.0) GO TO 407
       A(I)=B(I)*(HROOT-E(I))*2.0*RDF(I)/(DD(I+1)-DD(I-1))
       GO TO 406
  407  A(I)=0.0
  406  CONTINUE
C      ------------------------------------------------------------------
C------COMPUTATION OF TRIDIAGONAL MATRIX MAIN BODY
 38    DO 42 I=2,K                                                       A 158
       POT=(DD(I+1)-DD(I-1))/(2.0*DELT)                                  B 159
       DLXA=(DD(I)-DD(I-1))                                              B 160
       DLXB=(DD(I+1)-DD(I))                                              B 161
       BB=C(I)*POT/TT+B(I)/DLXB+B(I-1)/DLXA                              B 162
       DA=(C(I)*POT+G(I)+(B(I)/DLXB)*(TM*(G(I+1)-G(I))-DLXB)+(B(I-1)/DLXA B 162 1
      1)*(TM*(G(I-1)-G(I))+DLXA)+A(I)*(DD(I+1)-DD(I-1))*0.5)/TT           B 162 2
       IF(I-2)390,390,40
  390  IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 394
       DA=DA-((B(I-1)/DLXA)*(TM*(G(I-1)-G(I))+DLXA))/TT+EOR/TT
       BB=BB-B(I-1)/DLXA
       GO TO 393
  394  DA=DA+H(I-1)*B(I-1)/DLXA
  393  F(I)=DA/BB
       E(I)=(B(I)/DLXB)/BB
       GO TO 42                                                          B 166 1
 40    IF (I-K) 41,43,43                                                 A 167
 41    E(I)=(B(I)/DLXB)/(BB-(B(I-1)/DLXA)*E(I-1))                        A 168
       F(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))          B 169
   42  CONTINUE                                                          B 170
 43    BB=BB-TAA*B(I)/DLXB
       DA=DA+TAA*(B(I)/DLXB)*((G(I)-G(I+1))*TM+DLXB)/TT+TBB*B(I)/DLXB*H( B 172
      1KK)                                                               B 173
       H(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))          B 174
 44    I=I-1                                                             B 174 1
       H(I)=E(I)*H(I+1)+F(I)                                             A 175
       IF (I-2) 45,45,44                                                 A 176
 45    IF(TAA-1.0)47,46,46                                               A 177
 46    H(KK)=H(K)+DD(KK)-DD(K)
 47    DO 60 I=2,KK                                                      B 178
 300   IF (H(I)-HWET-DD(I)) 60,60,55
 55    H(I)=HWET+DD(I)
 60    CONTINUE
                                                                         A 197
```

```
C---COMPUTATION OF WATER CONTENTS AS A FUNCTION OF PRESSURES JUST COMP  A 199
      IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 1005
      WFDD=EOR
      H(1)=(EOR*DD(2)/B(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
      GO TO 134
 1005 WFDD=B(1)*((H(1)-H(2))*TT+(G(1)-G(2))*TM+DD(2))/DD(2)             B 189
 134  I=1
 62   IF (H(I)-G(I)) 65,116,65
65    NHI=54                                                            A 206
      NLO=1                                                             A 207
      J=25                                                              A 208
66    IF (H(I)-P(J)) 67,72,68                                           A 209
67    NHI=J                                                             A 210
      GO TO 69                                                          A 211
68    NLO=J                                                             A 212
69    JT=J                                                              A 213
      J=(NHI-NLO)/2+NLO                                                 A 214
      IF (J-JT) 66,70,66                                                A 215
70    IF (H(I)-P(J)) 71,72,72                                           A 216
71    J=J-1                                                             A 217
72    WAT=(H(I)-P(J))*DELW/(P(J+1)-P(J))+T(J)                           A 218
      W(I)=WAT
      GO TO 117
116   W(I)=Y(I)                                                         A 300
  117 DO 268 I=2,KK
268   W(I)=C(I)*(H(I)-G(I))+Y(I)
      GO TO 269
269   SUM3=0.0
      SUM2=0.0                                                          A 326
      SUM1=0.0
      DO 131 I=2,K                                                      A 327
      SUM1=W(I)+SUM1                                                    A 328
      SUM2=Y(I)+SUM2                                                    A 329
      IF (ABS(SUM1-SUM2)-ABS(SUM3)) 131,131,130                         A 330
130   SUM3=SUM1-SUM2                                                    A 331
131   CONTINUE                                                          A 332
      IF (ABS(SUM3)-ABS(CONO))63,63,132
 132  IF(DELT-DETT*0.1)63,63,133
  133 DELT=0.5*DELT
      GO TO 38                                                          A 336
   63 SUM1=0.0
      SUM2=0.0
      DO 800 I=2,K
      SUM1=W(I)*(DD(I+1)-DD(I-1))/2.+SUM1
  800 SUM2=Y(I)*(DD(I+1)-DD(I-1))/2.+SUM2
      CWF=SUM1-PIT
      WFRDD=(SUM1-SUM2)/DELT
      WFUU=B(NB)*((H(NB)-H(NB+1))*TT+(G(NB)-G(NB+1))*TM+DD(NB+1)-DD(NB))
     1/(DD(NB+1)-DD(NB))
      CUMS=WFDD*DELT+CUMS                                               A 341
      CUMB=WFUU*DELT+CUMB
      SUMA=SUMA+SINK*DELT
      CWFLX=(SUM1-SUM2)                                                A 343
      KB=K-1
C     ------------------------------------------------------------------
      DO 444 I=1,KK
      CSG(I)=CS(I)
      MSO(I)=MS(I)
      SNO(I)=SN(I)
      CLO(I)=CL(I)
      HCO(I)=HC(I)
      SUO(I)=SU(I)
      CSX(I)=CSO(I)
      MGSX(I)=MGSO(I)
 444  CONTINUE
      STIM=STIM+DELT
      KB=K-1
C     MASS FLOW OF DIFFERENT IONIC SPECIES
      DO 920 I=1,KB
      DELX=(DD(I+2)-DD(I))/2.0
      WFRU=(B(I)*((H(I)-H(I+1))*TT+(G(I)-G(I+1))*TM+DD(I+1)-DD(I))*DELT)
     1/(DD(I+1)-DD(I))
      WFRD=(B(I+1)*((H(I+1)-H(I+2))*TT+(G(I+1)-G(I+2))*TM*DD(I+2)-DD(I+1
     J))*DELT)/(DD(I+2)-DD(I+1))
  254 IF(ABS(WFRU).LT.0.0001.AND.ABS(WFRD).LT.0.0001)GO TO 920
      CL1=CLO(I)
      CL2=CLO(I+1)
      CL3=CLO(I+2)
      CL4=W(I+1)
      CL5=Y(I+1)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      CL(I+1)=CL6
      CL1=SUO(I)
      CL2=SUO(I+1)
      CL3=SUO(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      SU(I+1)=CL6
      CL1=HCO(I)
      CL2=HCO(I+1)
      CL3=HCO(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      HC(I+1)=CL6
      CL1=CSG(I)
      CL2=CSG(I+1)
      CL3=CSG(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      CS(I+1)=CL6
      CL1=MSO(I)
      CL2=MSO(I+1)
      CL3=MSO(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      MS(I+1)=CL6
      CL1=SNO(I)
      CL2=SNO(I+1)
      CL3=SNO(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      SN(I+1)=CL6
      CL1=CSX(I)
      CL2=CSX(I+1)
      CL3=CSX(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      CSO(I+1)=CL6
      CL1=MGSX(I)
      CL2=MGSX(I+1)
      CL3=MGSX(I+2)
      CALL SALT (CL1,CL2,CL3,CL4,CL5,CL6,WFRU,WFRD,DELX,I,FOR)
      MGSO(I+1)=CL6
      SE(I+1)=CS(I+1)+MS(I+1)+SN(I+1)+CSO(I+1)+MGSO(I+1).
      TCA(I+1)=CS(I+1)+CSO(I+1)
      TMG(I+1)=MS(I+1)+MGSO(I+1)
      LS=I+1
      IF(STIM.LT.1.0)GO TO 920
  475 WA=W(I+1)
      CSA=CS(I+1)
      MSA=MS(I+1)
      SNA=SN(I+1)
      SUA=SU(I+1)
      CLA=CL(I+1)
      HCA=HC(I+1)
      CEA=CE(I+1)
      MEA=ME(I+1)
      ENA=EN(I+1)
      CSP=CSO(I+1)
      MSP=MGSO(I+1)
      CAP=CAL(I+1)
      CASA=CAS(I+1)
      SEA=SE(I+1)
      CALL EXCH(CSA,MSA,SNA,SUA,CLA,HCA,CEA,MEA,ENA,CSP,MSP,CASA,CAP,WA,
     *SEA,AM,AC,SAM,SAC)
      CS(I+1)=CSA
      MS(I+1)=MSA
      SN(I+1)=SNA
      SU(I+1)=SUA
      CL(I+1)=CLA
      HC(I+1)=HCA
      CE(I+1)=CEA
      ME(I+1)=MEA
      EN(I+1)=ENA
      CSO(I+1)=CSP
      MGSO(I+1)=MSP
      CAL(I+1)=CAP
      CAS(I+1)=CASA
      SE(I+1)=SEA
      IF(CS(I+1).LT.0.0)CS(I+1)=0.0
      IF(MS(I+1).LT.0.0)MS(I+1)=0.0
      IF(SN(I+1).LT.0.0)SN(I+1)=0.0
      IF(SU(I+1).LT.0.0)SU(I+1)=0.0
      IF(CAS(I+1).LT.0.0)CAS(I+1)=0.0
      IF(CSO(I+1).LT.0.0)CSO(I+1)=0.0
      TCA(I+1)=CS(I+1)+CSO(I+1)
      TMG(I+1)=MS(I+1)+MGSO(I+1)
 970  CONTINUE
      IF(STIM.GE.1.0)STIM=0.0
C-------------------------------------------------------------------
      DO 704 I=1,KK                                                  B 3454
704   SD(I)=SE(I)*W(I)
706   IF(EOR-0.0)136,136,135
135   RUNOF=(EOR-WFDD)*DELT+RUNOF                                    A 345
136   TIME=TIME+DELT                                                 A 346
      IF (LL-MM) 138,137,137                                         A 347
  137 CALL PLOT (KK,WATH,W,DD,SMAX,SD)
      WRITE (6,166) (H(I),I=1,KK)                                    A 349
      WRITE(6,166)(SE(I),I=1,KK)
      WRITE(6,166)(A(I),I=2,K)
      WRITE(6,911)
      WRITE(6,111)(CS(I),MS(I),SN(I),SU(I),CL(I),HC(I),CE(I),ME(I),EN(I)
     J,CAS(I),SE(I),I=1,LS)
      WRITE(6,2001)
 2001 FORMAT(1H ,2X,'CASO',6X,'MGSO',6X,'CAL',7X,'TCA',7X,'TMG')
      WRITE(6,2000)(CSO(I),MGSO(I),CAL(I),TCA(I),TMG(I),I=1,LS)
      LL=0                                                           A 352
      WRITE (6,184)
  138 WRITE (6,111) TIME,CWF,EOR,HROOT,RUNOF,CUMS,CUMB,SUMA,WFRDD,WFUU,S
     1E(20)
      IF (SUM3-0.0) 139,301,139
  301 DELT=2.0*DELT
      GO TO 145
139   TW=ABS(CONQ*DELT/SUM3)                                         A 357
140   IF (TW-0.1*DETT) 141,142,142                                   A 359
  141 TW=0.1*DETT
      GO TO 144
  142 IF(TW-1000.0*DETT)144,144,143
 143  TW=1000.0*DETT
  144 IF(TW.GT.2.0*DELT) GO TO 301
      DELT=TW
C----TEST TO SEE IF EVAP OR RAIN INTENSITY (EOR) HAS CHANGED         A 365
145   IF(TIME-V(KC+1))148,147,148
147   CALL PLOT (KK,WATH,W,DD,SMAX,SD)                               A 371
      WRITE (6,166) (H(I),I=1,KK)
      WRITE(6,166)(SE(I),I=1,KK)
 2000 FORMAT(5E10.4)
      WRITE(6,911)
      WRITE(6,111)(CS(I),MS(I),SN(I),SU(I),CL(I),HC(I),CE(I),ME(I),EN(I)
     1,CAS(I),SE(I),I=1,KK)
      WRITE(6,2001)
      WRITE(6,2000)(CSO(I),MGSO(I),CAL(I),TCA(I),TMG(I),I=1,KK)
      WRITE (6,166) TIME,CWF,EOR,HROOT,RUNOF,CUMS,CUMB,SUMA,WFRDD,WFUU
C     -------------------------------------------------------------- A 375
      DELT=DETT
      EOR=V(KC+2)
      SE(1)=SF(KC+2)
      ET=TET(KC+2)
      MS(1)=MF(KC+2)
      CS(1)=CF(KC+2)
      SN(1)=SNF(KC+2)
      CL(1)=CLF(KC+2)
      SU(1)=SUF(KC+2)
      CSO(1)=CSOF(KC+2)
      MGSO(1)=MGSF(KC+2)
      HC(1)=HCF(KC+2)
      KC=KC+2
C     ----------------------------------------------------------------
      IF(TIME.LT.324.0.OR.TIME.GE.339.) GO TO 151
      SN(2)=SN(2)+(630.5555/W(2))
      CL(2)=CL(2)+(630.5555/W(2))
      GO TO 151
148   IF(TIME+DELT-V(KC+1))151,151,149
149   DELT=V(KC+1)-TIME
151   LL=LL+1
      IF (TIME-CUMT) 153,152,152
152   IF (ML-LMM) 162,162,1
153   Y(1)=(W(1)+Y(1))*0.5
      J=(Y(1)-T(1))/DELW+1.0
      BB=(Y(1)-T(J))/DELW
      IF (EOR-0.0) 155,156,155
155   G(1)=(P(J+1)-P(J))*BB+P(J)
156   DO 161 I=2,KK
      J=(W(I)-T(1))/DELW+1.0
      BB=(W(I)-T(J))/DELW
      G(I)=(P(J+1)-P(J))*BB+P(J)
      TW=(W(I)-Y(I))+W(I)
      IF (TW-WATH) 157,157,159
157   IF (TW-WATL) 158,160,160
158   TW=WATL
      GO TO 160
159   TW=WATH
160   Y(I)=W(I)
      W(I)=TW
      SS(I)=SE(I)
161   CONTINUE
      SS(1)=SE(1)
      GO TO 16
162   STOP
163   FORMAT (20I3)
165   FORMAT (7E10.4)
166   FORMAT (10F12.5)
  111 FORMAT (11F12.4)
  169 FORMAT(1H ,' K MM IER NB ND')
170   FORMAT (119H   WATER     POTENTIAL    CONDUCTIVITY DIFFUSIVITY
     1C(I)       DEPTH          W-DEPTH      H-DEPTH      RDF-DEPTH   SE-DEPTH)
172   FORMAT (53H   HDRY            HWET          WATL          WATH         C8)
174   FORMAT (54H  TIME END   SOIL FLUX    ET FLUX      SALT CONC.          )
180   FORMAT (66H  DELX           DETT          GRAVY          CONQ          DELW
     1        TIME)
181   FORMAT (66H   TT              CUMT          TAA           HLOW          HHI
     1        RRES)
184   FORMAT (1H ,'  TIME          CWF           EOR           HROOT          RUN
     1OF         CUMS           CUMB          TRANS.        WFRDD          WFUU
     2SE(20)')
 911  FORMAT(120H       CS            MS              SN              SU            C
     YL          HC              CF              ME              EN         GYPSUM    )
      END
      SUBROUTINE PLOT(N.WMAX.WVALUE.XVALUE.TMAX.TVALUE)
      DIMENSION ALINE(101).WVALUE(25).XVALUE(25).TVALUE(25)
      DATA FILL.AXIS.CHAR.CHAR.SAME/1H .1H..1HW.1HS.1H*/
      WRITE (6.7) WMAX.TMAX
      DO 1 J=1.101
1     ALINE(J)=AXIS
      WRITE (6.8) (ALINE(K).K=1.101)
      DO 2 J=1.101
2     ALINE(J)=FILL
      ALINE(1)=AXIS
      DO 4 L=1.N
      J=100.0*(WVALUE(L)/WMAX)+1.5
      JJ=100.0*(TVALUE(L)/TMAX)+1.5
      IF(J.LT.1) J=1
      IF(J.GT.101) J=101
      IF(JJ.LT.1) JJ=1
      IF(JJ.GT.1C1) JJ=101
      IF (J-JJ)10.11.10
11    ALINE (J)=SAME
      GO TO 12
10    ALINE (J)=CHAR
      ALINE(JJ)=CHAR
   12 WRITE(6.9) XVALUE(L).WVALUE(L).TVALUE(L).(ALINE(K).K=1.101)
      ALINE(JJ)=FILL
      ALINE(J)=FILL
   55 ALINE(1)=AXIS
4     CONTINUE
      DO 5 J=1.101
5     ALINE(J)=AXIS
      WRITE (6.8) (ALINE(K).K=1.101)
      RETURN
    7 FORMAT (24H  X VALUE WVALUE  SVALUE.5X.17H  MAX WAT CONT IS.F7.4.'
     1  MAX SALT CONCENTRATION IS'.F9.2.1H )
8     FORMAT (31X.101A1)
   9  FORMAT(1H .F6.1.F9.4.F8.2.7H        .101A1)
      END


      SUBROUTINE EXCH(A.F.S.G.H.HCO3.ET.CT.SAT.CASO.AGSO.XXT.CAL.PW1.SEA
     M.AM.AC.SAM.SAC)
      DIMENSION AM(27).AC(27).SAM(26).SAC(26)
      DOUBLE PRECISION ZZZ
      MH=1
      IG=1
      PW1=PW1*100.0/1.16
      B=100000.0/PW1
      B1=PW1
      A=A/(1000.0*2.0)
      F=F/(1000.0*2.0)
      G=G/(1000.0*2.0)
      S=S/1000.0
      H=H/1000.0
      HCO3=HCO3/1000.
      AGSO=AGSO/(1000.*2.)
      CASO=CASO/(1000.*2.)
C     DA IS K(CA-NA)EXCHANGE COEFFCIENT
      DA=4.5377
      D=0.25*5.0/SEA
      U=SQRT(2.0*(A+F+G)+0.5*(S+H+HCO3))
      IF(U**2.LT.0.003)GO TO 100
      CALL ACOF(AM.AC.SAM.SAC.U.ADI.AMO)
      ASA=ADI*AMO**2.0
      GO TO 101
  100 ASA=EXP(-7.0242*U/(1.0+U))
  101 IF(CAL)1000.602.603
 602  IK=1
      AAA=452.
  614 ZE=AAA/(B1**1.68)
      GO TO 24
```

```
613 IK=2
    ZE=(-1.68*ALOG(B1)-4.46)*2.3
    ZE=EXP(ZE)/ASA
24  A1=A
    IF(XXT)4,4,26
4   U=SQRT(2.0*(A+F+G)+0.5*(S+H+HCO3))
    IF(U**2.LT.0.003)GO TO 102
    CALL ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
    AA=ADI**2
    GO TO 103
102 AA=EXP(-9.366*U/(1.0+U))
103 IF(2.4E-5-A*G*AA)26,18,18
26  X=0.0
    U=SQRT(2.0*(A+F+G)+0.5*(S+H+HCO3))
    IF(U**2.LT.0.003)GO TO 104
    CALL ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
    EX=1.0/(ADI**2)
    GO TO 105
104 EX=EXP(9.366*U)/(1.0+U))
105 BB=A+G
    CC=A*G-(2.4E-5)*EX
    R=SQRT(BB*BB-4.0*CC)
    X=(-BB+R)/2.0
    CAS1=4.897E-3-CASO
    DEL=B*XXT-CAS1
    IF(DEL-X)27,28,28
27  X=XXT*B
    XXT=0.0
    CAS1=0.0
    A=A+X
    G=G+X
    U=SQRT(2.0*(A+F+G)+0.5*(S+H+HCO3))
    IF(U**2.LT.0.003)GO TO 106
    CALL ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
    AA=ADI**2
    GO TO 7
106 AA=EXP(-9.366*U/(1.+U))
7   BB=-(4.9E-3+AA*A+AA*G)
    CC=AA*A*G-4.9E-3*CASO
    XXXX=BB*BB-4.0*AA*CC
    IF(XXXX)35,35,36
35  X1=0.0
    GO TO 37
36  X1=(-BB-SQRT(XXXX))/(2.0*AA)
37  CASO=CASO+X1
    A=A-X1
    G=G-X1
    GO TO 44
18  IF(G)1,1,6
6   IF(A)1,1,7
1   IF(CASO)44,44,7
28  A=A+X
    G=G+X
    XXT=XXT-X/B
    CASO=CASO+CAS1
    XXT=XXT-CAS1/B
44  A2=A
    IT=1
    IH=1
    MX=1
    IF(S)80,181,80
181 IF(SAT)80,515,80
40  IJ=2
404 IF(SAT-ET)402,403,403
402 Z=SAT/10.
    Z1=Z
    GO TO 5
403 Z=ET/10.
    Z1=Z
5   U=SQRT(2.0*(A+F+G)+0.5*(S+H+HCO3))
```

```
      IF(U**2.LT.0.003)GO TO 107
      CALL ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
      EX=ADI/AMO**2
      GO TO 108
  107 EX=EXP((-2.341*U)/(1.0+U))
  108 AA=-4.0*DA*DA*G*B
      BB=4.0*B*(EX+2.0*DA*DA*ET*B*DA*DA*S)
      CC=4.0*EX*(A+SAT*B)-4.0*DA*DA*B*ET*(B*ET+2.0*S)-DA*DA*S*S
      DD=SAT*EX*(4.0*A*SAT*B)+2.0*DA*DA*ET*S*(2.0*B*ET+S)
      EE=SAT*SAT*A*EX-DA*DA*S*S*ET*ET
 81   ZZ=-((((AA*Z+BB)*Z+CC)*Z+DD)*Z+EE)
      ZZZ=(((4.0*AA*Z+3.0*BB)*Z+2.0*CC)*Z+DD)
      ZZ=ZZ/ZZZ
      IF(ZZ-0.0)302,303,302
 303  IF(Z-0.0)302,515,302
  302 ZZZ=ZZ/Z
      Z=Z+ZZ
      IF(IH.GE.5)GO TO 83
      IH=IH+1
      IF(DABS(ZZZ)-0.001)83,83,81
 83   IF(Z.GE.0.0)GO TO 305
      IF(SAT.LT.ABS(Z*2.0))Z=SAT/2.0
  515 A=A+B*Z
      IF(A)510,510,512
  552 SAT=SAT-2.*Z
  551 ET=ET+Z
  550 S=S+2.*B*Z
  510 A=A-B*Z
      Z=-Z
      IF(MX.GE.5)GO TO 512
      MX=MX+1
      GO TO 81
  512 S=S-2.0*B*Z
      IF(MX.GE.5)GO TO 513
      MX=MX+1
      IF(S)550,550,513
  513 ET=ET-Z
      IF(MX.GE.5)GO TO 514
      MX=MX+1
      IF(ET)551,551,514
  514 SAT=SAT+2.0*Z
      IF(MX.GE.5)GO TO 515
      MX=MX+1
      IF(SAT)552,552,515
  515 A3=A
      BB=A+B*(CT+D*FT)+D*F
      AA=B*(1.0-D)
      CC=(A*CT-D*F*FT)
      R=SQRT(BB*BB-4.0*AA*CC)
      Y=(-BB+R)/(2.0*AA)
      A=A+B*Y
      F=F-B*Y
      ET=ET-Y
      CT=CT+Y
      IF(G)790,790,791
  791 IF(F)790,790,792
  792 IF(U**2.LT.0.003)GO TO 109
      CALL ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
      AA=ADI**2
      GO TO 110
  109 AA=EXP(-9.366*U/(1.+U))
  110 BB=-(5.9E-3+AA*F+AA*G)
      CC=AA*F*G-5.9E-3*AGSO
      XXXX=BB*BB-4.0*AA*CC
      IF(XXXX)793,793,794
  793 X1=0.0
      GO TO 795
  794 X1=(-BB-SQRT(XXXX))/(2.0*AA)
 795  AGSO=AGSO+X1
      F=F-X1
      G=G-X1
```

```
790 CONTINUE
    GO TO (600,601),IK
601 AA=4.0
    BB=4.0*HCO3+A
    CC=HCO3**2+4.0*A*HCO3
    DD=A*HCO3**2-ZE
    IF(HCO3-A)61,61,62
61  Z=-HCO3/4.
    GO TO 650
62  Z=-A/2.
650 Z1=Z
63  ZZ=-(((AA*Z+BB)*Z+CC)*Z+DD)
    ZZZ=((3.0*AA*Z+2.0*BB)*Z+CC)
    IF(ZZ-0.0)300,301,300
301 IF(ZZZ-0.0)300,600,300
300 ZZ=ZZ/ZZZ
    ZZZ=ZZ/Z
    Z=Z+ZZ
    IF(IT.GE.5)GO TO 64
    IT=IT+1
    IF(DABS(ZZZ)-.001)64,64,63
64  A=A+Z
    HCO3=HCO3+2.*Z
    IF(HCO3)752,752,651
752 HCO3=HCO3-2.*Z
    A=A-Z
    Z=-Z1
    GO TO 63
651 IF(A)752,752,753
753 CAL=CAL-Z
600 ZX=A*HCO3**2
    IF(ZX-ZE)606,605,605
605 IK=2
606 DEL=A-A1
    IF(IG.GE.5)GO TO 8
    IG=IG+1
    IF(DEL+1.0E-5)24,48,48
48  IF(DEL-1.0E-5)49,49,24
49  DEL=A-A2
    IF(DEL+1.0E-5)24,50,50
50  IF(DEL-1.0E-5)51,51,24
51  DEL=A-A3
    IF(DEL+1.0E-5)24,52,52
52  IF(DEL-1.0E-5)8,8,24
8   AP=A
1000 CONTINUE
67  CONTINUE
    A=A*1000.0*2.0
    F=F*1000.0*2.0
    S=S*1000.0
    G=G*1000.0*2.0
    H=H*1000.0
    HCO3=HCO3*1000.
    CASO=CASO*1000.0*2.0
    AGSO=AGSO*1000.*2.0
    SEA=A+F+S+CASO+AGSO
    RETURN
    END


    SUBROUTINE EQFXCH(CA,AMG,SOS,CL,SO,HCO3,ES,CS,SAS,CASO,AGSO,SEA,AM
   Y,AC,SAM,SAC)
    DIMENSION AM(27),AC(27),SAM(26),SAC(26)
    CA=CA/(1000.0*2.0)
    AMG=AMG/(1000.0*2.0)
    SOS=SOS/1000.
    SO=SO/(1000.0*2.0)
    CL=CL/1000.
    HCO3=HCO3/1000.0
```

```
      EC=0.11E-03
C     DA IS K(NA-CA) OR 1.0/K(CA-NA) EXCHANGE COEFFCIENT
      DA=0.3115
      D=0.25+5.0/SEA
      CASO=0.0
      U=SQRT(2.0*(CA+AMG+SO)+0.5*(SOS+HCO3+CL))
      AGSO=0.0
      IF(U**2.LT.0.003)GO TO 42
      CALL ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
      ACT2=ADI**2
      GO TO 150
   42 ACT2=EXP(-9.366*U/(1.0+U))
  150 IF(SO)1000,713,712
  712 AA=ACT2*ACT2
      BB=ACT2*(10.8E-3+(ACT2*(AMG+CA-SO)))
      CC=28.91E-6+(ACT2*(AMG*4.9E-3+(CA*5.9E-3)-(SO*10.8E-3)))
      DD=-SO*28.91E-6
  840 Z=SO/2.
  850 Z1=Z
  863 ZZ=-(((AA*Z+BB)*Z+CC)*Z+DD)
      ZZZ=((3.0*AA*Z+2.0*BB)*Z+CC)
      ZZ=ZZ/ZZZ
      ZZZ=ZZ/Z
      Z=Z+ZZ
      IF(ABS(ZZZ)-.001)880,880,863
  880 SOT=SO
      SO=Z
      IF(SO)710,710,711
  710 SO=SOT
      Z=Z1
      GO TO 863
  711 CASX=SO*CA*ACT2/(4.9E-3+ACT2*SO)
      CX=CA-CASX
      AGSX=SO*AMG*ACT2/(5.9E-3+ACT2*SO)
      AMX=AMG-AGSX
      UU=SQRT(2.0*(CX+AMX+SO)+0.5*(SOS+HCO3+CL))
      IF(ABS(UU/U-1.)-1.0E-4)40,40,41
   41 U=UU
      SO=SOT
      GO TO 42
   40 CASO=CASX
      AGSO=AGSX
      CA=CX
      AMG=AMX
  713 ACT1=SQRT(ACT2)
      ACTM=SQRT(ACT1)
      ACTM=SQRT(ACTM)
      CA=CA*2.
      AMG=AMG*2.
C--CA,MG,ARE IN EQUIVALENT/LITER
      ES=EC/((ACTM*SOS/(DA*SQRT(ACT1*CA)))+1.+(D*ACT1*AMG/(ACT1*CA)))
      SAS=ACTM*SOS*ES/(SQRT(ACT1*CA)*DA)
      CS=EC-ES-SAS
      ES=ES/2.
      CS=CS/2.
      CA=CA*1000.0
      AMG=AMG*1000.0
C--CA,MG,ARE IN ME/LITER
      SOS=SOS*1000.0
      CL=CL*1000.0
      SO=SO*1000.0*2.0
      HCO3=HCO3*1000.0
      CASO=CASO*1000.0*2.0
      AGSO=AGSO*1000.0*2.0
      SEA=CA+AMG+SOS+CASO+AGSO
      WRITE(6,100)CA,AMG,SOS,CL,SO,HCO3,ES,CS,SAS,AGSO,CASO,SEA
  100 FORMAT(12E10.4)
 1000 RETURN
      END
      SUBROUTINE SALT(A,B,C,D,E,F,WFRU,WFRD,DELX,J,EOR)
C     SE AND SS ARE NEW AND OLD CONCENTRATIONS
      DIMENSION SS(3),W(3),SE(3),Y(3)
      I=1
      SS(I)=A
      SS(I+1)=B
      SS(I+2)=C
      W(I+1)=D
      Y(I+1)=E
      IF(J.EQ.1)GO TO 201
      IF(WFRU.GE.0.0.AND.WFRD.GE.0.0)GO TO 205
      IF(WFRU.LE.0.0.AND.WFRD.LE.0.0)GO TO 209
      IF(WFRU.GE.0.0.AND.WFRD.LE.0.0)GO TO 208
      IF(WFRU.LE.0.0.AND.WFRD.GE.0.0)GO TO 210
  205 SE(I+1)=(SS(I+1)*Y(I+1)+(SS(I)*WFRU-SS(I+1)*WFRD)/DELX)/W(I+1)
      GO TO 200
  201 IF(EOR-0.0)203,204,202
  203 IF(WFRD.GT.0.0)GO TO 206
  207 SE(2)=(SS(2)*Y(2)-(SS(3)*WFRD)/DELX)/W(2)
      GO TO 200
  206 SE(2)=(SS(2)*Y(2)-(SS(2)*WFRD)/DELX)/W(2)
      GO TO 200
  204 IF(WFRD.LT.0.0)GO TO 207
      GO TO 206
  202 IF(WFRD.GT.0.0)GO TO 205
  208 SE(I+1)=(SS(I+1)*Y(I+1)+(SS(I)*WFRU-SS(I+2)*WFRD)/DELX)/W(I+1)
      GO TO 200
  209 SE(I+1)=(SS(I+1)*Y(I+1)+(SS(I+1)*WFRU-SS(I+2)*WFRD)/DELX)/W(I+1)
      GO TO 200
  210 SE(I+1)=(SS(I+1)*Y(I+1)+(SS(I+1)*WFRU-SS(I+1)*WFRD)/DELX)/W(I+1)
  200 IF(SE(I+1).LT.0.0)SE(I+1)=SS(I+1)
      F=SE(I+1)
      RETURN
      END


      SUBROUTINE ACOF(AM,AC,SAM,SAC,U,ADI,AMO)
      DIMENSION AM(27),AC(27),SAM(26),SAC(26)
      U=U**2
      IF(U.LE.15.0)GO TO 1
      ADI=587.0
      GO TO 2
    1 DO 751 I=1,27
      IF(U.GT.AM(I))GO TO 751
      AG=U-AM(I-1)
      ADI=AC(I-1)+((AC(I)-AC(I-1))*AG)/(AM(I)-AM(I-1))
      GO TO 2
  751 CONTINUE
    2 IF(U.LE.5.0)GO TO 3
      AMO=1.295
      GO TO 4
    3 DO 604 I=1,26
      IF(U.GT.SAM(I))GO TO 604
      AG=U-SAM(I-1)
      AMO=SAC(I-1)+((SAC(I)-SAC(I-1))*AG)/(SAM(I)-SAM(I-1))
      GO TO 4
  604 CONTINUE
    4 RETURN
      END
```

# APPENDIX C

## DATA AND RESULTS

Table 34. Rain, irrigation and actual evapotranspiration data for alfalfa in 1971. Rain and irrigation data were measured by rain gauge, evapotranspiration data were measured by the lysimeter.

| Date | Rain cm | Irrigation cm | ET-cm East Lysimeter | ET-cm West Lysimeter | Average ET-cm | Cumulative cm |
|---|---|---|---|---|---|---|
| May 15, 1971 | | | .84 | .84 | .84 | .84 |
| May 16, 1971 | | 1.63 | .38 | -.25 | .07 | .91 |
| May 17, 1971 | .20 | | .05 | .09 | .07 | .98 |
| May 18, 1971 | | | .04 | .15 | .10 | 1.08 |
| May 19, 1971 | | | .53 | .42 | .48 | 1.56 |
| May 20, 1971 | | | .48 | .42 | .45 | 2.01 |
| May 21, 1971 | | | .32 | .42 | .37 | 2.38 |
| May 22, 1971 | | 1.77 | 1.01 | .42 | .72 | 3.10 |
| May 23, 1971 | | 1.57 | .37 | -.35 | .01 | 3.11 |
| May 24, 1971 | | | .09 | -.07 | .01 | 3.12 |
| May 25, 1971 | | | .53 | .64 | .58 | 3.70 |
| May 26, 1971 | | | .85 | .42 | .64 | 4.34 |
| May 27, 1971 | | | .16 | .48 | .32 | 4.66 |
| May 28, 1971 | 2.79 | | .00 | .00 | .00 | 4.66 |
| May 29, 1971 | | | .65 | .65 | .65 | 5.31 |
| May 30, 1971 | | | .71 | .71 | .71 | 6.02 |
| May 31, 1971 | | | .77 | .77 | .77 | 6.75 |
| June 1, 1971 | | | .16 | .37 | .26 | 7.05 |
| June 2, 1971 | | | .48 | .26 | .37 | 7.42 |
| June 3, 1971 | | 2.99 | .32 | .16 | .24 | 7.66 |
| June 4, 1971 | | | .08 | .08 | .08 | 7.74 |
| June 5, 1971 | | | .08 | .08 | .08 | 7.82 |
| June 6, 1971 | | | .53 | .37 | .45 | 8.27 |
| June 7, 1971 | | | .53 | .37 | .45 | 8.72 |
| June 8, 1971 | | | .48 | .37 | .42 | 9.14 |
| June 9, 1971 | | | .53 | .37 | .45 | 9.59 |
| June 10, 1971 | | 4.83 | .27 | .05 | .16 | 9.75 |
| June 11, 1971 | | | .59 | .00 | .29 | 10.04 |
| June 12, 1971 | | | 1.27 | .42 | .85 | 10.89 |
| June 13, 1971 | | | .24 | .50 | .37 | 11.26 |
| June 14, 1971 | | | .71 | .45 | .58 | 11.84 |
| June 15, 1971 | | | .58 | .48 | .53 | 12.37 |

Table 34. Continued

| Date | Rain cm | Irrigation cm | ET-cm East Lysimeter | ET-cm West Lysimeter | Average ET-cm | Cumulative cm |
|---|---|---|---|---|---|---|
| June 16, 1971 | | | .58 | .64 | .61 | 12.98 |
| June 17, 1971 | | | .53 | .42 | .48 | 13.46 |
| June 18, 1971 | | | .64 | .58 | .61 | 14.07 |
| June 19, 1971 | | | .90 | .85 | .87 | 14.94 |
| June 20, 1971 | | | .90 | .60 | .75 | 15.69 |
| June 21, 1971 | .03 | | .90 | .73 | .81 | 16.50 |
| June 22, 1971 | | | .54 | .54 | .54 | 17.04 |
| June 23, 1971 | | | .54 | .54 | .54 | 17.58 |
| June 24, 1971 | | | .47 | .47 | .47 | 18.05 |
| June 25, 1971 | | | .27 | .47 | .37 | 18.42 |
| June 26, 1971 | .13 | | .00 | .00 | .00 | 18.42 |
| June 27, 1971 | | | .26 | .37 | .32 | 18.74 |
| June 28, 1971 | | | .42 | .62 | .52 | 19.06 |
| June 29, 1971 | | 6.05 | .00 | .00 | .00 | 19.06 |
| June 30, 1971 | .27 | | .00 | .00 | .00 | 19.06 |
| July 1, 1971 | | | .51 | .51 | .51 | 19.57 |
| July 2, 1971 | | | .62 | .62 | .62 | 20.19 |
| July 3, 1971 | | | .70 | .70 | .70 | 20.89 |
| July 4, 1971 | | | .72 | .72 | .72 | 21.61 |
| July 5, 1971 | | | .67 | .67 | .67 | 22.28 |
| July 6, 1971 | | | .64 | .64 | .64 | 22.92 |
| July 7, 1971 | | | .67 | .67 | .67 | 23.59 |
| July 8, 1971 | | | .65 | .65 | .65 | 24.24 |
| July 9, 1971 | | | .67 | .67 | .67 | 24.91 |
| July 10, 1971 | | 6.73 | .67 | .67 | .67 | 25.58 |
| July 11, 1971 | | | .76 | .76 | .76 | 26.34 |
| July 12, 1971 | | | .90 | .98 | .94 | 27.28 |
| July 13, 1971 | | | .87 | .93 | .90 | 28.18 |
| July 14, 1971 | | | .64 | .74 | .69 | 28.87 |
| July 15, 1971 | | | .55 | .55 | .55 | 29.42 |
| July 16, 1971 | | | .36 | .84 | .60 | 30.02 |
| July 17, 1971 | | | .48 | .68 | .58 | 30.60 |
| July 18, 1971 | | | .15 | 1.17 | .66 | 31.26 |
| July 19, 1971 | .08 | | .00 | .00 | .00 | 31.26 |
| July 20, 1971 | | 7.24 | .00 | .00 | .00 | 31.26 |
| July 21, 1971 | .10 | | .00 | .00 | .00 | 31.26 |
| July 22, 1971 | | | .00 | .00 | .00 | 31.26 |
| July 23, 1971 | | | .53 | .80 | .62 | 31.88 |
| July 24, 1971 | | | .47 | .64 | .55 | 32.43 |
| July 25, 1971 | | | .46 | .80 | .63 | 33.06 |

Table 34. Continued

| Date | Rain cm | Irrigation cm | ET-cm East Lysimeter | ET-cm West Lysimeter | Average ET-cm | Cumu-lative cm |
|---|---|---|---|---|---|---|
| July 26, 1971 | .03 |  | .45 | .73 | .59 | 33.65 |
| July 27, 1971 |  |  | .45 | .73 | .59 | 34.24 |
| July 28, 1971 |  |  | .52 | .85 | .68 | 34.92 |
| July 29, 1971 |  | 2.57 | .86 | .70 | .78 | 35.70 |
| July 30, 1971 |  |  | .72 | 1.02 | .87 | 36.57 |
| July 31, 1971 |  |  | .64 | .95 | .79 | 37.86 |
| Aug. 1, 1971 |  |  | - | - | .63 | 37.99 |
| Aug. 2, 1971 |  |  | - | - | .56 | 38.55 |
| Aug. 3, 1971 |  |  | .36 | .50 | .43 | 38.98 |
| Aug. 4, 1971 |  |  | -.21 | .53 | .16 | 39.14 |
| Aug. 5, 1971 |  |  | - | - | .15 | 39.29 |
| Aug. 6, 1971 |  |  | .26 | .35 | .31 | 39.60 |
| Aug. 7, 1971 |  |  | .05 | .66 | .36 | 39.96 |
| Aug. 8, 1971 |  |  | .26 | .37 | .32 | 40.28 |
| Aug. 9, 1971 |  |  | .22 | .38 | .30 | 40.58 |
| Aug. 10, 1971 |  |  | .32 | .46 | .39 | 40.97 |
| Aug. 11, 1971 |  |  | .32 | .66 | .49 | 41.46 |
| Aug. 12, 1971 |  |  | .48 | .69 | .58 | 42.04 |
| Aug. 13, 1971 |  |  | .53 | .67 | .60 | 42.64 |
| Aug. 14, 1971 |  |  | .41 | .90 | .66 | 43.30 |
| Aug. 15, 1971 |  |  | .58 | .90 | .74 | 44.04 |
| Aug. 16, 1971 |  |  | .58 | .88 | .73 | 44.77 |
| Aug. 17, 1971 |  |  | - | - | .69 | 45.46 |
| Aug. 18, 1971 |  | 10.18 | - | - | .00 | 45.46 |
| Aug. 19, 1971 |  |  | - | - | .51 | 45.97 |
| Aug. 20, 1971 |  |  | .16 | .74 | .45 | 46.42 |
| Aug. 21, 1971 |  |  | .18 | .69 | .43 | 46.85 |
| Aug. 22, 1971 |  |  | .27 | .65 | .46 | 47.31 |
| Aug. 23, 1971 |  |  | - | - | .45 | 47.76 |
| Aug. 24, 1971 |  |  | - | - | .46 | 48.22 |
| Aug. 25, 1971 |  |  | - | - | .35 | 48.57 |
| Aug. 26, 1971 |  |  | .33 | .33 | .33 | 48.90 |
| Aug. 27, 1971 |  |  | .29 | .29 | .29 | 49.19 |
| Aug. 28, 1971 |  |  | .46 | .46 | .46 | 49.65 |
| Aug. 29, 1971 |  |  | .55 | .55 | .55 | 50.20 |
| Aug. 30, 1971 |  | 9.25 | .28 | .28 | .28 | 50.48 |
| Aug. 31, 1971 |  |  | .50 | .50 | .50 | 50.98 |

Table 34. Continued

| Date | Rain cm | Irrigation cm | ET-cm East Lysimeter | ET-cm West Lysimeter | Average ET-cm | Cumulative cm |
|---|---|---|---|---|---|---|
| Sept. 1, 1971 | | | .49 | .49 | .49 | 51.47 |
| Sept. 2, 1971 | .74 | | .56 | .53 | .55 | 52.02 |
| Sept. 3, 1971 | | | .42 | .42 | .42 | 52.44 |
| Sept. 4, 1971 | | | .43 | .43 | .43 | 52.87 |
| Sept. 5, 1971 | | | .48 | .48 | .48 | 53.35 |
| Sept. 6, 1971 | .05 | | .00 | .00 | .00 | 53.35 |
| Sept. 7, 1971 | | | .54 | .54 | .54 | 53.89 |
| Sept. 8, 1971 | 1.21 | | .00 | .00 | .00 | 53.89 |
| Sept. 9, 1971 | | | .18 | .92 | .55 | 54.44 |
| Sept. 10, 1971 | | | .48 | .48 | .48 | 54.92 |
| Sept. 11, 1971 | | | .52 | .52 | .52 | 55.44 |

Table 35. Average soil water content (θ) of six sites in the field, as measured by the neutron probe, and equivalent depth of water in the soil profile for alfalfa in 1971, and for oats in 1970.

| Date | Depth - cm | | | | | | Equiv. Water Depth (cm) |
|---|---|---|---|---|---|---|---|
| | 30 | 45 | 75 | 105 | 135 | 165 | |
| May 13, 1971 | .153 | .268 | .267 | .276 | .308 | .373 | 46.407 |
| May 31, 1971 | .290 | .284 | .247 | .262 | .350 | .388 | 52.556 |
| June 9, 1971 | .259 | .283 | .264 | .281 | .378 | .408 | 53.766 |
| June 11, 1971 | .312 | .314 | .294 | .289 | .375 | .403 | 57.456 |
| June 22, 1971 | .202 | .248 | .238 | .273 | .327 | .396 | 47.947 |
| June 29, 1971 | .315 | .303 | .260 | .283 | .382 | .413 | 56.600 |
| July 8, 1971 | .223 | .259 | .246 | .277 | .377 | .405 | 51.121 |
| July 10, 1971 | .321 | .322 | .280 | .275 | .371 | .400 | 56.990 |
| July 19, 1971 | .231 | .266 | .253 | .279 | .380 | .413 | 52.128 |
| July 21, 1971 | .313 | .318 | .310 | .307 | .386 | .414 | 59.255 |
| July 22, 1971 | .301 | .305 | .302 | .311 | .386 | .412 | 58.286 |
| Aug. 3, 1971 | .252 | .276 | .264 | .294 | .385 | .414 | 54.116 |
| Aug. 16, 1971 | .197 | .244 | .246 | .285 | .381 | .413 | 50.304 |
| Aug. 18, 1971 | .316 | .322 | .320 | .334 | .402 | .419 | 61.151 |
| Aug. 19, 1971 | .302 | .310 | .311 | .343 | .404 | .421 | 60.386 |
| Aug. 29, 1971 | .244 | .279 | .272 | .308 | .389 | .420 | 54.845 |
| Aug. 30, 1971 | .321 | .325 | .325 | .335 | .400 | .419 | 61.540 |
| Aug. 31, 1971 | .306 | .314 | .316 | .343 | .398 | .420 | 60.641 |
| Sept. 8, 1971 | .275 | .288 | .280 | 313 | .389 | .411 | 56.370 |
| July 31, 1970 | .197 | .295 | .257 | .295 | .378 | .462 | |
| Aug. 2, 1970 | .163 | .273 | .262 | .295 | .380 | .463 | |
| Aug. 4, 1970 | .127 | .250 | .257 | .290 | .377 | .455 | |
| Aug. 8, 1970 | .112 | .233 | .247 | .288 | .378 | .462 | |

Table 36. Average soil water content (θ) of two sites in two lysimeters as measured by the neutron probe, and equivalent depth of water in the soil profile for alfalfa in 1971.

| Date | Depth - cm | | | | | Equivalent Water Depth (cm) |
|---|---|---|---|---|---|---|
| | 30 | 45 | 60 | 75 | 82.5 | |
| May 13, 1971 | .205 | .262 | .279 | .302 | .325 | 22.433 |
| May 31, 1971 | .283 | .283 | .292 | .312 | .333 | 26.109 |
| June 9, 1971 | .256 | .277 | .301 | .326 | .337 | 25.310 |
| June 11, 1971 | .311 | .314 | .332 | .344 | .353 | 28.765 |
| June 22, 1971 | .207 | .250 | .278 | .311 | .322 | 22.362 |
| June 29, 1971 | .315 | .308 | .294 | .304 | .307 | 27.369 |
| July 8, 1971 | .204 | .233 | .258 | .280 | .287 | 21.020 |
| July 10, 1971 | .325 | .317 | .302 | .281 | .280 | 27.500 |
| July 19, 1971 | .204 | .226 | .249 | .265 | .264 | 20.371 |
| July 21, 1971 | .309 | .316 | .327 | .332 | .328 | 28.283 |
| July 22, 1971 | .299 | .295 | .308 | .323 | .325 | 27.155 |
| Aug. 3, 1971 | .221 | .226 | .239 | .257 | .257 | 20.704 |
| Aug. 16, 1971 | .154 | .162 | .177 | .189 | .185 | 14.826 |
| Aug. 18, 1971 | .311 | .311 | .318 | .272 | .252 | 26.767 |
| Aug. 19, 1971 | .290 | .291 | .300 | .298 | .284 | 25.957 |
| Aug. 29, 1971 | .212 | .224 | .232 | .237 | .228 | 19.765 |
| Aug. 30, 1971 | .318 | .323 | .329 | .327 | .314 | 28.585 |
| Aug. 31, 1971 | .296 | .296 | .310 | .320 | .315 | 26.972 |
| Sept. 8, 1971 | .255 | .250 | .258 | .277 | .273 | 23.041 |

Table 37. Average soil water content (θ) of four sites in the field, as measured by the gamma probe, for alfalfa in 1971.

| Date | Depth - cm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 90 | 105 | 120 |
| May 14 | .260 | .264 | .236 | .240 | .264 | .271 | .269 | .281 | .241 | .232 | .264 | .273 | .305 |
| May 31 | .319 | .297 | .252 | .230 | .241 | .255 | .241 | .244 | .225 | .220 | .255 | .267 | .293 |
| June 9 | .231 | .234 | .205 | .216 | .238 | .261 | .249 | .244 | .220 | .230 | .257 | .283 | .325 |
| June 11 | .333 | .290 | .284 | .264 | .275 | .298 | .274 | .293 | .249 | .246 | .263 | .294 | .317 |
| June 22 | .165 | .202 | .149 | .163 | .202 | .228 | .223 | .223 | .224 | .228 | .265 | .299 | .328 |
| June 30 | .299 | .299 | .252 | .250 | .246 | .263 | .224 | .237 | .217 | .229 | .269 | .306 | .347 |
| July 8 | .211 | .246 | .226 | .234 | .249 | .269 | .258 | .264 | .257 | .254 | .287 | .324 | .366 |
| July 10 | .361 | .342 | .302 | .291 | .287 | .316 | .278 | .380 | .229 | .235 | .258 | .296 | .336 |
| July 19 | .192 | .231 | .191 | .209 | .234 | .257 | .258 | .248 | .234 | .241 | .273 | .305 | .339 |
| July 21 | .325 | .313 | .267 | .277 | .289 | .314 | .309 | .312 | .280 | .301 | .304 | .333 | .364 |
| July 21 | .327 | .326 | .289 | .292 | .293 | .339 | .328 | .329 | .294 | .304 | .324 | .351 | .378 |
| July 22 | .309 | .302 | .265 | .271 | .276 | .318 | .300 | .318 | .285 | .288 | .311 | .356 | .379 |
| Aug. 3 | .241 | .251 | .220 | .233 | .250 | .269 | .268 | .277 | .265 | .265 | .293 | .344 | .364 |
| Aug. 16 | .159 | .186 | .171 | .192 | .226 | .244 | .237 | .253 | .228 | .247 | .289 | .334 | .361 |
| Aug. 18 | .298 | .271 | .260 | .233 | .236 | .289 | .279 | .295 | .264 | .276 | .274 | .320 | .376 |
| Aug. 19 | .329 | .330 | .274 | .280 | .282 | .332 | .324 | .345 | .306 | .309 | .334 | .379 | .417 |
| Aug. 29 | .208 | .228 | .196 | .208 | .250 | .263 | .268 | .281 | .247 | .293 | .291 | .359 | .366 |
| Aug. 30 | .353 | .346 | .303 | .290 | .304 | .334 | .334 | .363 | .321 | .322 | .320 | .395 | .403 |
| Aug. 31 | .322 | .322 | .282 | .265 | .277 | .312 | .316 | .354 | .310 | .319 | .322 | .400 | .421 |
| Sept. 8 | .287 | .285 | .240 | .244 | .264 | .276 | .277 | .292 | .291 | .283 | .290 | .368 | .366 |

Table 38. Average soil water content (θ) of two sites in two lysimeters as measured by the gamma probe, for alfalfa in 1971.

| Date | Depth - cm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
| May 14 | .270 | .265 | .262 | .280 | .286 | .300 | .324 | .326 | .332 | .346 | .346 |
| May 31 | .312 | .311 | .28 | .294 | .284 | .287 | .311 | .307 | .306 | .333 | .330 |
| June 9 | .226 | .248 | .238 | .256 | .273 | .281 | .316 | .311 | .317 | .352 | .350 |
| June 11 | .326 | .319 | .315 | .336 | .305 | .330 | .348 | .356 | .347 | .363 | .370 |
| June 22 | .161 | .181 | .184 | .218 | .238 | .242 | .262 | .275 | .290 | .313 | .323 |
| June 30 | .289 | .294 | .274 | .307 | .288 | .296 | .301 | .312 | .283 | .321 | .325 |
| July 8 | .220 | .236 | .239 | .253 | .265 | .274 | .297 | .312 | .295 | .327 | .325 |
| July 10 | .351 | .340 | .351 | .339 | .371 | .334 | .293 | .280 | .287 | .225 | .296 |
| July 19 | .180 | .186 | .183 | .206 | .240 | .232 | .255 | .270 | .243 | .285 | .274 |
| July 21 | .297 | .307 | .315 | .324 | .325 | .315 | .338 | .332 | .317 | .327 | .355 |
| July 21 | .290 | .304 | .285 | .311 | .323 | .311 | .335 | .325 | .331 | .342 | .372 |
| July 22 | .281 | .304 | .272 | .300 | .296 | .296 | .312 | .311 | .319 | .352 | .372 |
| Aug. 3 | .220 | .223 | .209 | .272 | .233 | .240 | .244 | .263 | .258 | .285 | .269 |
| Aug. 16 | .141 | .158 | .156 | .180 | .174 | .175 | .186 | .190 | .174 | .205 | .203 |
| Aug. 18 | .287 | .296 | .295 | .322 | .311 | .309 | .345 | .326 | .306 | .258 | .245 |
| Aug. 19 | .290 | .309 | .302 | .324 | .314 | .328 | .331 | .331 | .313 | .326 | .270 |
| Aug. 29 | .168 | .184 | .191 | .208 | .219 | .220 | .225 | .233 | .235 | .242 | .223 |
| Aug. 30 | .327 | .311 | .324 | .361 | .339 | .343 | .360 | .356 | .341 | .361 | .325 |
| Aug. 31 | .310 | .312 | .308 | .311 | .318 | .315 | .342 | .347 | .334 | .354 | .341 |
| Sept. 8 | - | - | - | - | - | - | - | - | - | - | - |

Table 39. Climatic data and potential evapotranspiration as calculated by Penman modified method for alfalfa in 1971.

| Date | Radiation Total ly/min | Radiation Net ly/min | Radiation Long ly/min | Wind mi/day | Temperature Dry Bulb °C | Temperature Wet Bulb °C | Temperature Soil °C | Vapour Pressure Saturated MB | Vapour Pressure Actual MB | ET-Pen cm/day | ET-cum. cm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May 15 | .27 | .14 | .07 | 71.9 | 18.61 | 11.67 | 9.50 | 21.44 | 17.41 | .30 | .30 |
| May 16 | .50 | .33 | .08 | 84.1 | 16.11 | 10.83 | 9.50 | 18.31 | 15.25 | .59 | .89 |
| May 17 | .22 | .08 | .09 | 160.6 | 11.11 | 6.67 | 10.00 | 13.21 | 10.65 | .19 | 1.08 |
| May 18 | .43 | .25 | .10 | 62.8 | 6.11 | 2.50 | 10.75 | 9.42 | 7.35 | .37 | 1.45 |
| May 19 | .49 | .30 | .09 | 74.2 | 8.20 | 4.30 | 9.65 | 10.86 | 8.61 | .47 | 1.92 |
| May 20 | .60 | .43 | .08 | 90.0 | 12.30 | 6.39 | 9.25 | 14.40 | 10.90 | .51 | 2.43 |
| May 21 | .39 | .22 | .09 | 77.7 | 10.00 | 5.56 | 8.50 | 12.27 | 9.71 | .36 | 2.79 |
| May 22 | .57 | .38 | .08 | 173.0 | 15.40 | 7.08 | 8.00 | 17.50 | 12.70 | .74 | 3.53 |
| May 23 | .43 | .25 | .10 | 76.4 | 9.44 | 5.83 | 7.75 | 11.82 | 9.74 | .40 | 3.93 |
| May 24 | .51 | .33 | .09 | 67.6 | 9.44 | 6.94 | 8.25 | 11.82 | 10.38 | .49 | 4.42 |
| May 25 | .45 | .27 | .09 | 64.4 | 11.70 | 7.78 | 8.00 | 13.71 | 11.46 | .45 | 4.87 |
| May 26 | .50 | .31 | .09 | 5.7 | 14.40 | 9.17 | 9.50 | 16.45 | 13.39 | .53 | 5.40 |
| May 27 | .42 | .29 | .07 | .3 | 18.75 | 10.55 | 8.63 | 21.60 | 16.89 | .49 | 5.89 |
| May 28 | .40 | .23 | .09 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 6.32 |
| May 29 | .40 | .23 | .08 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 6.75 |
| May 30 | .40 | .23 | .09 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 7.18 |
| May 31 | .40 | .23 | .08 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 7.61 |
| June 1 | .31 | .17 | .08 | 86.4 | 16.53 | 10.00 | 8.50 | 18.80 | 15.02 | .35 | 7.96 |
| June 2 | .38 | .22 | .08 | 66.5 | 15.00 | 8.89 | 10.75 | 17.05 | 13.51 | .41 | 8.37 |
| June 3 | .35 | .24 | .08 | 59.5 | 17.64 | 10.95 | 10.87 | 20.10 | 16.30 | .50 | 8.87 |
| June 4 | .42 | .26 | .07 | 108.5 | 17.79 | 11.24 | 10.00 | 20.37 | 16.57 | .56 | 9.43 |
| June 5 | .43 | .26 | .08 | 94.5 | 16.66 | 10.97 | 10.50 | 18.97 | 15.67 | .49 | 9.92 |
| June 6 | .48 | .30 | .08 | 79.4 | 14.72 | 10.28 | 10.00 | 16.74 | 14.16 | .53 | 10.45 |
| June 7 | .48 | .30 | .08 | 79.4 | 14.72 | 10.28 | 10.00 | 16.74 | 14.16 | .53 | 10.98 |
| June 8 | .44 | .28 | .07 | 45.0 | 19.00 | 11.67 | 10.50 | 21.99 | 17.73 | .54 | 11.52 |
| June 9 | .42 | .27 | .07 | 62.0 | 20.80 | 13.00 | 10.75 | 24.40 | 20.00 | .55 | 12.07 |
| June 10 | .28 | .15 | .07 | 60.0 | 19.00 | 13.20 | 11.50 | 21.20 | 18.20 | .31 | 12.38 |

Table 39. Climatic data and potential evapotranspiration as calculated by Penman modified method for alfalfa in 1971.

| Date | Radiation |  |  | Wind | Temperature |  |  | Vapour Pressure |  | ET-Pen | ET-cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Total ly/min | Net ly/min | Long ly/min | mi/day | Dry Bulb °C | Wet Bulb °C | Soil °C | Saturated MB | Actual MB | cm/day | cm |
| May 15 | .27 | .14 | .07 | 71.9 | 18.61 | 11.67 | 9.50 | 21.44 | 17.41 | .30 | .30 |
| May 16 | .50 | .33 | .08 | 84.1 | 16.11 | 10.83 | 9.50 | 18.31 | 15.25 | .59 | .89 |
| May 17 | .22 | .08 | .09 | 160.6 | 11.11 | 6.67 | 10.00 | 13.21 | 10.65 | .19 | 1.08 |
| May 18 | .43 | .25 | .10 | 62.8 | 6.11 | 2.50 | 10.75 | 9.42 | 7.35 | .37 | 1.45 |
| May 19 | .49 | .30 | .09 | 74.2 | 8.20 | 4.30 | 9.65 | 10.86 | 8.61 | .47 | 1.92 |
| May 20 | .60 | .43 | .08 | 90.0 | 12.30 | 6.39 | 9.25 | 14.40 | 10.90 | .51 | 2.43 |
| May 21 | .39 | .22 | .09 | 77.7 | 10.00 | 5.56 | 8.50 | 12.27 | 9.71 | .36 | 2.79 |
| May 22 | .57 | .38 | .08 | 173.0 | 15.40 | 7.08 | 8.00 | 17.50 | 12.70 | .74 | 3.53 |
| May 23 | .43 | .25 | .10 | 76.4 | 9.44 | 5.83 | 7.75 | 11.82 | 9.74 | .40 | 3.93 |
| May 24 | .51 | .33 | .09 | 67.6 | 9.44 | 6.94 | 8.25 | 11.82 | 10.38 | .49 | 4.42 |
| May 25 | .45 | .27 | .09 | 64.4 | 11.70 | 7.78 | 8.00 | 13.71 | 11.46 | .45 | 4.87 |
| May 26 | .50 | .31 | .09 | 5.7 | 14.40 | 9.17 | 9.50 | 16.45 | 13.39 | .53 | 5.40 |
| May 27 | .42 | .29 | .07 | .3 | 18.75 | 10.55 | 8.63 | 21.60 | 16.89 | .49 | 5.89 |
| May 28 | .40 | .23 | .09 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 6.32 |
| May 29 | .40 | .23 | .08 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 6.75 |
| May 30 | .40 | .23 | .09 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 7.18 |
| May 31 | .40 | .23 | .08 | 84.8 | 14.86 | 9.44 | 10.00 | 16.89 | 13.76 | .43 | 7.61 |
| June 1 | .31 | .17 | .08 | 86.4 | 16.53 | 10.00 | 8.50 | 18.80 | 15.02 | .35 | 7.96 |
| June 2 | .38 | .22 | .08 | 66.5 | 15.00 | 8.89 | 10.75 | 17.05 | 13.51 | .41 | 8.37 |
| June 3 | .35 | .24 | .08 | 59.5 | 17.64 | 10.95 | 10.87 | 20.10 | 16.30 | .50 | 8.87 |
| June 4 | .42 | .26 | .07 | 108.5 | 17.79 | 11.24 | 10.00 | 20.37 | 16.57 | .56 | 9.43 |
| June 5 | .43 | .26 | .08 | 94.5 | 16.66 | 10.97 | 10.50 | 18.97 | 15.67 | .49 | 9.92 |
| June 6 | .48 | .30 | .08 | 79.4 | 14.72 | 10.28 | 10.00 | 16.74 | 14.16 | .53 | 10.45 |
| June 7 | .48 | .30 | .08 | 79.4 | 14.72 | 10.28 | 10.00 | 16.74 | 14.16 | .53 | 10.98 |
| June 8 | .44 | .28 | .07 | 45.0 | 19.00 | 11.67 | 10.50 | 21.99 | 17.73 | .54 | 11.52 |
| June 9 | .42 | .27 | .07 | 62.0 | 20.80 | 13.00 | 10.75 | 24.40 | 20.00 | .55 | 12.07 |
| June 10 | .28 | .15 | .07 | 60.0 | 19.00 | 13.20 | 11.50 | 21.20 | 18.20 | .31 | 12.38 |

Table 39. Continued

| Date | Radiation |  |  | Wind | Temperature |  |  | Vapour Pressure |  | ET-Pen | ET-cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Total ly/min | Net ly/min | Long ly/min | mi/day | Dry Bulb °C | Wet Bulb °C | Soil °C | Saturated MB | Actual MB | cm/day | cm |
| June 11 | .28 | .15 | .07 | 60.0 | 19.00 | 13.20 | 11.50 | 21.20 | 18.20 | .31 | 12.69 |
| June 12 | .46 | .30 | .08 | 60.0 | 16.90 | 11.11 | 12.00 | 19.30 | 15.92 | .57 | 13.26 |
| June 13 | .50 | .32 | .08 | 47.1 | 17.17 | 11.30 | 11.80 | 19.50 | 16.10 | .56 | 13.82 |
| June 14 | .43 | .27 | .07 | 60.0 | 20.00 | 13.82 | 10.12 | 23.82 | 19.88 | .53 | 14.35 |
| June 15 | .43 | .27 | .06 | 54.5 | 21.88 | 14.28 | 9.67 | 26.21 | 21.78 | .56 | 14.91 |
| June 16 | .41 | .27 | .07 | 60.9 | 21.50 | 14.52 | 9.70 | 25.62 | 21.58 | .52 | 15.43 |
| June 17 | .43 | .27 | .08 | 61.6 | 18.61 | 12.78 | 12.50 | 21.44 | 18.06 | .50 | 15.93 |
| June 18 | .38 | .24 | .06 | 72.4 | 24.52 | 15.56 | 12.30 | 30.60 | 25.45 | .52 | 16.45 |
| June 19 | .34 | .22 | .05 | 62.8 | 26.00 | 16.20 | 12.58 | 33.48 | 27.76 | .54 | 16.99 |
| June 20 | .48 | .33 | .06 | 52.4 | 23.06 | 15.56 | 12.25 | 28.13 | 23.75 | .60 | 17.59 |
| June 21 | .48 | .33 | .06 | 52.4 | 23.06 | 15.56 | 12.25 | 28.13 | 23.75 | .60 | 18.19 |
| June 22 | .43 | .29 | .05 | 56.6 | 24.86 | 15.90 | 9.06 | 31.28 | 26.07 | .61 | 18.80 |
| June 23 | .39 | .27 | .04 | 123.0 | 26.75 | 15.00 | 13.00 | 37.90 | 30.43 | .58 | 19.38 |
| June 24 | .41 | .28 | .05 | 82.9 | 26.70 | 14.75 | 13.00 | 34.85 | 27.87 | .66 | 20.04 |
| June 25 | .46 | .32 | .05 | 83.1 | 26.05 | 14.50 | 13.70 | 33.55 | 26.84 | .70 | 20.74 |
| June 26 | .51 | .36 | .05 | 83.3 | 25.40 | 14.25 | 14.75 | 32.25 | 25.81 | .73 | 21.47 |
| June 27 | .32 | .20 | .05 | 100.6 | 25.56 | 14.17 | 13.50 | 32.58 | 25.95 | .47 | 21.94 |
| June 28 | .53 | .34 | .08 | 128.8 | 18.89 | 11.67 | 14.25 | 21.82 | 17.62 | .67 | 22.61 |
| June 29 | .42 | .28 | .06 | 126.4 | 23.72 | 14.44 | 15.60 | 29.26 | 23.86 | .62 | 23.23 |
| June 30 | .38 | .23 | .07 | 65.7 | 19.44 | 12.50 | 16.00 | 22.58 | 18.54 | .45 | 23.68 |
| July 1 | .43 | .29 | .06 | 65.0 | 22.43 | 12.12 | 15.75 | 27.18 | 21.19 | .64 | 24.32 |
| July 2 | .45 | .29 | .07 | 78.0 | 20.00 | 14.44 | 16.00 | 23.37 | 20.13 | .56 | 24.88 |
| July 3 | .45 | .29 | .07 | 78.6 | 19.44 | 14.72 | 15.50 | 22.58 | 19.83 | .54 | 25.42 |
| July 4 | .45 | .29 | .07 | 89.7 | 19.17 | 13.06 | 15.75 | 22.20 | 18.64 | .56 | 25.98 |
| July 5 | .45 | .29 | .07 | 93.0 | 19.44 | 13.33 | 16.00 | 22.58 | 19.03 | .55 | 26.53 |
| July 6 | .43 | .27 | .07 | 63.3 | 20.00 | 13.39 | 16.25 | 23.37 | 19.81 | .53 | 27.06 |
| July 7 | .42 | .27 | .07 | 94.6 | 20.28 | 14.72 | 16.00 | 23.77 | 20.54 | .53 | 27.59 |
| July 8 | .47 | .30 | .07 | 93.0 | 20.28 | 15.28 | 16.75 | 23.77 | 20.86 | .58 | 28.17 |

Table 39. Continued

| Date | Radiation |  |  | Wind | Temperature |  |  | Vapour Pressure |  | ET-Pen | ET-cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Total ly/min | Net ly/min | Long ly/min | mi/day | Dry Bulb °C | Wet Bulb °C | Soil °C | Saturated MB | Actual MB | cm/day | cm |
| July 9 | .43 | .27 | .07 | 62.1 | 19.17 | 13.89 | 16.50 | 22.20 | 19.12 | .51 | 28.68 |
| July 10 | .50 | .32 | .08 | 52.2 | 18.06 | 12.50 | 16.50 | 20.71 | 17.48 | .59 | 29.27 |
| July 11 | .51 | .33 | .08 | 52.2 | 18.89 | 13.06 | 16.50 | 21.81 | 18.42 | .61 | 29.88 |
| July 12 | .54 | .36 | .07 | 52.2 | 20.00 | 13.61 | 16.50 | 23.37 | 19.65 | .68 | 30.56 |
| July 13 | .53 | .36 | .07 | 71.4 | 20.58 | 15.00 | 16.50 | 24.18 | 20.94 | .67 | 31.23 |
| July 14 | .42 | .28 | .06 | 72.2 | 21.11 | 18.33 | 16.25 | 25.02 | 23.39 | .52 | 31.75 |
| July 15 | .44 | .30 | .06 | 68.4 | 21.39 | 18.89 | 16.25 | 25.44 | 23.98 | .55 | 32.30 |
| July 16 | .50 | .33 | .07 | 36.3 | 20.83 | 16.39 | 16.50 | 24.60 | 22.00 | .62 | 32.92 |
| July 17 | .49 | .34 | .05 | 43.7 | 25.00 | 18.06 | 16.25 | 31.55 | 27.48 | .68 | 33.60 |
| July 18 | .37 | .26 | .04 | 46.0 | 27.78 | 20.28 | 16.25 | 37.00 | 32.61 | .53 | 34.13 |
| July 19 | .29 | .17 | .06 | 52.4 | 22.78 | 18.06 | 16.50 | 27.66 | 24.90 | .34 | 34.47 |
| July 20 | .20 | .09 | .07 | 34.6 | 16.94 | 14.72 | 16.50 | 19.30 | 18.01 | .16 | 34.63 |
| July 21 | .31 | .16 | .08 | 15.0 | 15.00 | 13.75 | 16.50 | 17.05 | 16.32 | .27 | 34.90 |
| July 22 | .37 | .22 | .08 | 53.9 | 16.39 | 14.58 | 16.25 | 18.64 | 17.58 | .37 | 35.27 |
| July 23 | .31 | .17 | .07 | 67.2 | 17.78 | 15.00 | 16.50 | 20.35 | 18.73 | .32 | 35.59 |
| July 24 | .48 | .31 | .07 | 42.9 | 18.60 | 15.00 | 16.50 | 21.44 | 19.33 | .56 | 36.15 |
| July 25 | .48 | .32 | .07 | 42.9 | 19.17 | 15.00 | 16.25 | 22.20 | 19.77 | .58 | 36.73 |
| July 26 | .45 | .29 | .07 | 42.9 | 19.44 | 15.00 | 16.25 | 22.58 | 19.99 | .53 | 36.26 |
| July 27 | .45 | .29 | .07 | 45.0 | 20.00 | 15.56 | 16.25 | 23.37 | 20.78 | .54 | 37.80 |
| July 28 | .45 | .29 | .07 | 38.1 | 18.61 | 16.11 | 16.00 | 21.44 | 19.98 | .52 | 38.32 |
| July 29 | .48 | .32 | .07 | 35.6 | 18.06 | 17.78 | 16.00 | 20.71 | 20.55 | .55 | 38.87 |
| July 30 | .46 | .30 | .07 | 34.4 | 18.08 | 17.34 | 15.75 | 21.01 | 20.46 | .53 | 39.40 |
| July 31 | .44 | .28 | .07 | 33.2 | 18.10 | 16.90 | 15.75 | 21.31 | 20.37 | .51 | 39.91 |
| Aug. 1 | .42 | .26 | .07 | 32.0 | 18.12 | 16.46 | 15.75 | 21.61 | 20.28 | .49 | 40.40 |
| Aug. 2 | .40 | .25 | .07 | 30.8 | 18.14 | 16.02 | 15.75 | 21.91 | 20.19 | .47 | 40.87 |
| Aug. 3 | .38 | .23 | .07 | 29.8 | 19.17 | 15.56 | 15.75 | 22.20 | 20.09 | .43 | 41.30 |
| Aug. 4 | .42 | .25 | .08 | 48.4 | 15.56 | 13.33 | 15.50 | 17.67 | 16.38 | .43 | 41.73 |
| Aug. 5 | .28 | .15 | .08 | 50.7 | 17.22 | 13.61 | 15.50 | 19.65 | 17.55 | .28 | 42.01 |

Table 39. Continued

| Date | Radiation |  |  | Wind | Temperature |  |  | Vapour Pressure |  | ET-Pen | ET-cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Total ly/min | Net ly/min | Long ly/min | mi/day | Dry Bulb °C | Wet Bulb °C | Soil °C | Saturated MB | Actual MB | cm/day | cm |
| Aug. 6 | .37 | .24 | .06 | 43.9 | 23.89 | 16.67 | 15.50 | 29.55 | 25.34 | .48 | 42.49 |
| Aug. 7 | .36 | .25 | .04 | 60.9 | 28.89 | 18.33 | 15.75 | 39.39 | 33.21 | .55 | 43.04 |
| Aug. 8 | .24 | .15 | .04 | 63.6 | 27.78 | 17.78 | 16.00 | 37.00 | 31.16 | .35 | 43.39 |
| Aug. 9 | .24 | .15 | .04 | 63.6 | 27.78 | 17.78 | 16.00 | 37.00 | 31.16 | .35 | 43.74 |
| Aug. 10 | .36 | .23 | .06 | 56.7 | 22.22 | 15.00 | 16.50 | 26.76 | 22.55 | .46 | 44.20 |
| Aug. 11 | .47 | .31 | .07 | 47.6 | 21.67 | 13.61 | 16.50 | 25.87 | 21.19 | .60 | 44.80 |
| Aug. 12 | .39 | .24 | .07 | 69.7 | 22.22 | 13.89 | 17.25 | 26.76 | 21.91 | .50 | 45.30 |
| Aug. 13 | .43 | .27 | .07 | 57.9 | 20.83 | 14.17 | 17.75 | 24.59 | 20.71 | .54 | 45.84 |
| Aug. 14 | .43 | .27 | .07 | 60.7 | 20.28 | 13.89 | 17.75 | 23.77 | 20.05 | .52 | 46.36 |
| Aug. 15 | .41 | .27 | .06 | 46.9 | 23.06 | 14.72 | 17.75 | 28.13 | 23.27 | .54 | 46.90 |
| Aug. 16 | .43 | .29 | .05 | 41.0 | 26.11 | 16.39 | 18.00 | 33.65 | 27.97 | .60 | 47.50 |
| Aug. 17 | .48 | .34 | .05 | 26.9 | 26.11 | 16.39 | 18.25 | 33.65 | 27.97 | .69 | 48.19 |
| Aug. 18 | .34 | .20 | .07 | 8.7 | 20.56 | 14.31 | 17.75 | 24.18 | 20.54 | .39 | 48.58 |
| Aug. 19 | .35 | .19 | .09 | 82.7 | 15.00 | 12.08 | 18.50 | 17.05 | 15.35 | .34 | 48.92 |
| Aug. 20 | .29 | .15 | .08 | 41.8 | 15.83 | 12.78 | 18.75 | 17.99 | 16.21 | .27 | 49.19 |
| Aug. 21 | .37 | .22 | .07 | 49.6 | 18.06 | 14.72 | 18.50 | 20.71 | 18.67 | .40 | 49.59 |
| Aug. 22 | .42 | .27 | .06 | 37.3 | 21.11 | 15.83 | 18.25 | 25.02 | 21.94 | .51 | 50.10 |
| Aug. 23 | .44 | .28 | .07 | 58.3 | 20.56 | 15.83 | 18.00 | 24.18 | 21.43 | .54 | 50.64 |
| Aug. 24 | .37 | .22 | .07 | 48.1 | 18.89 | 14.44 | 18.00 | 21.82 | 19.23 | .41 | 51.05 |
| Aug. 25 | .45 | .29 | .07 | 32.3 | 19.17 | 14.44 | 17.75 | 22.20 | 19.45 | .53 | 51.58 |
| Aug. 26 | .19 | .08 | .07 | 21.5 | 18.33 | 15.56 | 18.00 | 21.07 | 19.45 | .15 | 51.73 |
| Aug. 27 | .30 | .17 | .07 | 39.4 | 18.61 | 16.11 | 18.25 | 21.44 | 19.98 | .30 | 52.03 |
| Aug. 28 | .30 | .18 | .06 | 40.7 | 21.39 | 17.50 | 18.00 | 25.44 | 23.17 | .34 | 52.37 |
| Aug. 29 | .38 | .24 | .06 | 40.8 | 22.22 | 18.33 | 17.50 | 26.76 | 24.48 | .47 | 52.84 |
| Aug. 30 | .40 | .25 | .06 | 75.0 | 20.28 | 16.67 | 17.50 | 23.77 | 21.66 | .48 | 53.32 |
| Sept. 1 | .45 | .30 | .06 | 62.5 | 22.50 | 17.22 | 17.50 | 27.20 | 24.12 | .59 | 54.18 |
| Sept. 2 | .43 | .27 | .07 | 60.0 | 19.44 | 15.00 | 17.00 | 22.58 | 19.99 | .51 | 54.69 |
| Sept. 3 | .41 | .24 | .09 | 100.8 | 12.50 | 9.72 | 17.00 | 14.49 | 12.88 | .40 | 55.09 |

Table 39. Continued

| Date | Radiation |  |  | Wind | Temperature |  |  | Vapour Pressure |  | ET-Pen | ET-cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Total ly/min | Net ly/min | Long ly/min | mi/day | Dry Bulb $^{o}$C | Wet Bulb $^{o}$C | Soil $^{o}$C | Saturated MB | Actual MB | cm/day | cm |
| Sept. 4 | .28 | .13 | .09 | 53.3 | 10.83 | 8.06 | 16.50 | 12.97 | 11.37 | .23 | 55.32 |
| Sept. 5 | .45 | .30 | .07 | 50.3 | 18.06 | 11.11 | 16.50 | 20.70 | 16.68 | .55 | 55.87 |
| Sept. 6 | .45 | .29 | .07 | 43.7 | 18.89 | 12.22 | 16.00 | 21.82 | 17.94 | .55 | 56.42 |
| Sept. 7 | .40 | .25 | .08 | 74.3 | 16.39 | 12.50 | 15.75 | 18.64 | 16.38 | .44 | 56.86 |
| Sept. 8 | .38 | .22 | .08 | 45.5 | 14.44 | 11.94 | 15.50 | 16.45 | 15.00 | .38 | 57.24 |
| Sept. 9 | .38 | .22 | .08 | 44.0 | 11.67 | 10.67 | 15.50 | 13.71 | 13.07 | .35 | 57.59 |
| Sept. 10 | .38 | .23 | .08 | 42.3 | 13.89 | 11.39 | 15.25 | 15.86 | 14.41 | .38 | 57.97 |
| Sept. 11 | .36 | .21 | .07 | 35.4 | 17.22 | 13.06 | 15.25 | 19.65 | 17.23 | .38 | 58.35 |

Table 40. Electrical conductivity (mmho/cm) of drain effluent measured periodically in the field with a portable conductivity meter in 1971.

| Date | Drain | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | Airport |
| June 10 | | | | 2050 | 1950 | | |
| 18 | | | | 1890 | 1950 | | |
| 24 | | | | 1830 | 1800 | 1560 | |
| 29 | | | | 1710 | 1640 | 1440 | |
| 30 | | | | 1690 | 1530 | 1330 | |
| July 2 | | | | 1840 | 1910 | 1660 | |
| 5 | | | | 1840 | 1770 | 1560 | |
| 6 | | | | 1750 | 1660 | 1520 | |
| 8 | | | | | 1670 | | |
| 9 | | | | | 1600 | 1890 | |
| 12 | | | | 1660 | 1640 | 1490 | |
| 13 | | | | 1730 | 1620 | 1500 | |
| 15 | | | | 1830 | 1630 | | |
| 19 | | | | 1740 | 1820 | 1470 | |
| 21 | | | 1910 | 1630 | 1610 | 1640 | |
| 22 | | | | 1770 | 1720 | 1680 | |
| 26 | | | | 1690 | 1650 | 1520 | |
| 27 | | | | 1420 | 1610 | 1290 | |
| 28 | | | | 1960 | 1660 | 1420 | |
| 29 | | | | 1790 | 1670 | 1470 | |
| 30 | | | | 1610 | 1540 | 1460 | |
| Aug. 2 | | | | 1660 | 1520 | 1360 | |
| 6 | | | | | 1490 | | |
| 12 | | | | | 1450 | | |
| 16 | | | | 1510 | 1390 | 1140 | |
| 17 | | 2340 | 2460 | 1650 | 1540 | 1520 | |
| 18 | | | 2220 | 1710 | 1550 | 1390 | |
| 19 | | | 1970 | 1750 | 1610 | 1450 | |
| 20 | | | | 1710 | 1560 | | |
| 21 | | | | 1710 | 1570 | | |
| 23 | | | | 1730 | 1550 | | |
| 24 | | | | 1700 | 1520 | | 1550 |
| 25 | | | | 1710 | 1540 | 1390 | |
| 26 | | | | 1610 | 1470 | 1350 | |
| 27 | | | | 1740 | 1590 | 1430 | |
| 28 | | | | 1710 | 1570 | | |
| 30 | | | | 1730 | 1570 | 1450 | |
| 31 | 3500 | | 1990 | 1710 | 1540 | 1420 | 1630 |

Table 40. Continued

| Date | Drain 1 | 2 | 3 | 4 | 5 | 6 | Airport |
|---|---|---|---|---|---|---|---|
| Sept. 1 | | | 1960 | 1770 | 1560 | 1440 | |
| 2 | | | | 1780 | 1560 | 1500 | |
| 3 | | | | 1750 | 1610 | | |
| 8 | | | | 1670 | 1530 | | |
| 9 | | | | 1670 | 1460 | | |
| 10 | | | | 1610 | 1450 | | 1550 |
| 13 | | | | | 1480 | | |
| 14 | | | | | 1540 | | |
| 15 | | | | | 1460 | | |
| 16 | | | | | 1440 | | |
| 17 | | | | | 1375 | | |
| 18 | | | | | 1370 | | |
| 19 | | | | | 1395 | | |
| 20 | | | | | 1400 | | |
| 21 | | | | | 1390 | | |
| 22 | | | | | 1390 | | |
| 23 | | | | | 1425 | | |

Table 41. Typical composition of Drain 5 effluent collected at one-hour intervals on August 4, 1971.

|  | $Ca^{++}$* (meq/1) | $Mg^{++}$ (meq/1) | $Na^{+}$ (meq/1) | $CO_3^{--}$ (meq/1) | $HCO_3^{-}$ (meq/1) | $Cl^{-}$ (meq/1) | $SO_4^{--}$ (meq/1) | $NO_3^{-}$ (ppm) | EC (µmho/cm) |
|---|---|---|---|---|---|---|---|---|---|
|  | 13.2 | 6.7 | 1.1 | 0.90 | 11.1 | 0.34 | 3.8 | 1.8 | 1362 |
|  | 12.4 | 6.7 | 1.1 |  | 12.0 | 0.34 | 3.4 | 1.4 | 1365 |
|  |  | 6.5 | 1.1 | 1.3 | 10.7 | 0.35 | 3.6 | 1.4 | 1376 |
|  |  | 6.7 | 1.1 | 1.9 | 10.3 | 0.35 | 3.9 | 1.4 | 1371 |
|  |  | 6.7 | 1.1 | 1.9 | 10.2 | 0.35 | 3.9 | 1.4 | 1370 |
|  |  | 6.6 | 1.2 | 1.1 | 10.7 | 0.45 | 3.9 | .9 | 1379 |
|  |  | 6.6 | 1.1 | 2.2 | 9.4 | 0.34 | 4.0 | 2.5 | 1373 |
|  |  | 7.2 | 1.1 | 1.9 | 10.1 | 0.40 | 4.0 | 1.3 | 1351 |
|  |  | 6.7 | 1.1 | 2.4 | 9.6 | 0.34 | 3.9 | 1.9 | 1342 |
|  | 12.0 | 7.6 | 1.1 | 1.1 | 10.9 | 0.34 | 3.9 | 1.9 | 1347 |
|  | 13.2 | 6.6 | 1.1 | 1.3 | 10.8 | 0.38 | 3.6 | 1.7 | 1338 |
|  |  | 6.9 | 1.1 | 1.9 | 10.4 | 0.38 | 3.8 | 1.9 | 1350 |
|  |  | 6.5 | 1.1 | 1.1 | 10.9 | 0.32 | 3.8 | 2.5 | 1359 |
|  |  | 6.6 | 1.2 | 1.1 | 11.2 | 0.35 | 3.8 | 1.8 | 1341 |
|  |  | 6.7 | 1.1 | 1.5 | 10.5 | 0.35 | 3.9 | 2.0 | 1334 |
|  |  | 6.7 | 1.1 | 1.3 | 11.1 | 0.35 | 3.7 | 1.9 | 1319 |
|  |  | 6.7 | 1.1 | 1.1 | 11.1 | 0.32 | 3.7 | 1.8 | 1351 |
|  |  | 6.7 | 1.1 | 1.9 | 10.6 | 0.35 | 3.2 | 2.7 | 1370 |
|  |  | 6.7 | 1.1 | 1.9 | 10.2 | 0.38 | 3.7 | 2.1 | 1358 |
|  |  | 6.7 | 1.1 | 1.3 | 10.7 | 0.38 | 3.7 | 2.4 | 1382 |
|  |  | 6.6 | 1.1 | 1.9 | 10.7 | 0.40 | 3.6 | 2.0 | 1380 |
|  |  | 6.7 | 1.1 | 2.0 | 10.4 | 0.40 | 3.8 | 2.1 | 1375 |
|  |  | 6.7 | 1.1 | 1.5 | 10.5 | 0.45 | 3.4 | 1.8 | 1375 |
| Average | 12.7 | 6.7 | 1.1 | 1.6 | 10.6 | 0.37 | 3.7 | 1.9 | 1359 |

*$Ca^{++}$ concentration = solubility of $CaSO_4$

Table 42. Piezometric data typical of conditions during the irrigation season on the Hullinger farm (6-29-71).

| Location | Water Table Depth (ft) 12 | 9 | 6 | Elev.* Top of Pipe | Location | Water Table Depth (ft) 12 | 9 | 6 | Elev.* Top of Pipe |
|---|---|---|---|---|---|---|---|---|---|
| 1W100N4 | 3.63 | 3.66 | 3.60 | 58.81 | 6E50-150 | 4.39 | 4.40 | 4.40 | 73.57 |
| 1W100N50 | 3.84 | 3.83 | 3.83 | 59.14 | 6E20-150 | 4.44 | 4.46 | 4.49 | 74.04 |
| 3W5N4 | 3.45 | 3.48 | 3.47 | 63.35 | 6E5-150 | 4.62 | 4.60 | 4.75 | 74.44 |
| 3W5N47 | 3.53 | 3.45 | 3.46 | 63.43 | 6W5-150 | 4.50 | 4.50 | 4.55 | 74.54 |
| 3W100N4 | 3.24 | 3.33 | 2.42 | 64.38 | 6W20-150 | 4.32 | 4.35 | 4.35 | 74.73 |
| 3W100N43 | 2.68 | 2.61 | 2.62 | 63.91 | 6W43-150 | 3.99 | 3.97 | 4.02 | 75.18 |
| 5W175N12 | 3.30 | 3.22 | 3.22 | 71.06 | 6W5-20 | 4.24 | 4.34 | 4.30 | 74.50 |
| 5W175N50 | 3.12 | 3.13 | 3.14 | 71.20 | 6W149-400 | 4.65 | 4.66 | 4.62 | 76.60 |
| 6W5N12 | 2.80 | 2.78 | 2.74 | 73.59 | 6W50-400 | 3.38 | 4.00 | 4.02 | 74.72 |
| 6W5N50 | 3.00 | 3.05 | 2.76 | 73.87 | 6W20-400 | 4.00 | 4.35 | 4.38 | 74.07 |
| 3W100-20 | 3.77 | 3.78 | 3.75 | 64.81 | 6W5-400 | 4.40 | 4.40 | 4.42 | 73.86 |
| 3W5-20 | 3.99 | 3.99 | 4.11 | 63.67 | 6E5-400 | 4.50 | 5.80 | 6.00 | 73.85 |
| 1W100-20 | 4.31 | 4.33 | 4.33 | 59.51 | 6E20-400 | 4.30 | 4.29 | 4.35 | 73.41 |
| 1W100-150 | 5.44 | 5.40 | 5.42 | 59.16 | 6E50-400 | 4.30 | 4.28 | 4.30 | 73.05 |
| 2W100-150 | 4.70 | 4.70 | 4.73 | 62.05 | 6E100-400 | 3.90 | 3.97 | 3.98 | 73.21 |
| 3E20-150 | 4.56 | 4.56 | 4.57 | 63.36 | 5W175-400 | 3.78 | 3.77 | 3.77 | 71.07 |
| 3E5-150 | 4.60 | 4.60 | 4.60 | 63.66 | 5W100-400 | 4.02 | 4.02 | 3.99 | 70.25 |
| 3W5-150 | 4.64 |  | 4.64 | 63.87 | 5W20-400 | 4.22 | 4.24 | 4.20 | 69.13 |
| 3W20-150 | 4.43 | 4.42 | 4.43 | 63.89 | 5W5-400 | 2.01 | 2.01 | 2.02 | 69.05 |
| 3W100-150 | 4.31 | 4.31 | 4.32 | 64.94 | 5E5-400 | 4.38 | 4.40 | 4.43 | 68.97 |
| 4W100-150 | 2.99 | 3.01 | 3.03 | 67.07 | 5E20-400 | 4.02 | 4.00 | 4.02 | 68.60 |
| 5W175-150 | 3.77 | 3.80 | 3.80 | 71.50 | 4W100-400 | 4.25 | 4.28 | 4.25 | 67.53 |
| 5W175-20 | 4.42 | 4.44 | 4.44 | 72.17 | 4W20-400 | 4.25 | 4.25 | 4.22 | 66.41 |

Table 42. Continued

| Location | Water Table Depth (ft) | | | Elev.* Top of Pipe | Location | Water Table Depth (ft) | | | Elev.* Top of Pipe |
|---|---|---|---|---|---|---|---|---|---|
| | 12 | 9 | 6 | | | 12 | 9 | 6 | |
| 4W5-400 | 4.29 | 4.30 | 4.32 | 66.25 | 1W5-400 | | 5.60 | 5.62 | 57.11 |
| 4E5-400 | 4.26 | 4.28 | 4.29 | 66.08 | 1W100-650 | 6.90 | 6.91 | | 58.85 |
| 4E20-400 | 4.19 | 4.19 | 4.20 | 65.73 | 2W100-650 | 6.03 | 6.03 | | 61.00 |
| 3W100-400 | 5.22 | 5.24 | 5.25 | 65.24 | 3E20-650 | 6.30 | 6.32 | | 63.05 |
| 3W50-400 | 5.50 | 5.58 | 5.59 | 64.65 | 3E5-650 | 6.30 | 6.30 | | 62.66 |
| 3W20-400 | 5.44 | 5.44 | 5.47 | 64.04 | 3W5-650 | 6.30 | 6.28 | | 62.81 |
| 3W5-400 | 5.53 | 5.51 | 5.50 | 63.80 | 3W20-650 | 6.20 | 6.18 | | 63.05 |
| 3E5-400 | 5.54 | 5.55 | 5.50 | 63.62 | 3W100-650 | 6.30 | 6.30 | | 64.66 |
| 3E20-400 | 5.35 | 5.38 | 5.35 | 63.14 | 4W100-650 | | 6.12 | | 68.59 |
| 3E50-400 | 5.34 | 5.30 | 5.35 | 62.68 | 5W175-650 | 5.72 | 5.77 | | 72.42 |
| 2W100-400 | 5.02 | 5.06 | 5.02 | 61.85 | 6E50-650 | 6.23 | 6.32 | | 74.22 |
| 2W20-400 | 5.01 | 5.02 | 5.01 | 60.47 | 6E20-650 | 6.57 | 6.58 | | 74.75 |
| 2W5-400 | 5.02 | 5.02 | 5.01 | 60.24 | 6E5-650 | 6.83 | 6.75 | | 75.11 |
| 2E5-400 | 5.25 | 5.20 | 5.20 | 60.09 | 6W5-650 | 6.73 | 6.73 | | 75.28 |
| 2E20-400 | 5.10 | 5.09 | 5.11 | 59.82 | 6W20-650 | 6.74 | 6.77 | | 75.44 |
| 1W100-400 | 5.23 | 5.24 | 5.23 | 58.37 | 6W50-650 | 6.80 | 6.81 | | 75.82 |
| 1W20-400 | 5.67 | 5.70 | 5.71 | 57.37 | 6W150-650 | 7.00 | 7.02 | | 77.23 |

*Elevation above mean sea level is value plus 5200 feet.

Table 43. Piezometric data typical of early spring conditions on the Hullinger farm (5-4-71).

| Location | Water Table Depth (ft) 12 | 9 | 6 | Elev.* Top of Pipe | Location | Water Table Depth (ft) 12 | 9 | 6 | Elev.* Top of Pipe |
|---|---|---|---|---|---|---|---|---|---|
| 1W100N4 | 6.27 | 6.27 | | 58.85 | 6E50-150 | 7.46 | 7.46 | | 73.57 |
| 1W100N50 | 6.59 | 6.61 | | 59.14 | 6E20-150 | 7.53 | 7.53 | | 74.04 |
| 3W5N4 | 6.14 | 6.14 | | 63.35 | 6E5-150 | 7.69 | 7.69 | | 74.44 |
| 3W5N47 | 6.21 | 6.20 | | 63.43 | 6W5-150 | 7.61 | 7.61 | | 74.54 |
| 3W100N4 | 5.94 | 5.94 | 5.94 | 64.38 | 6W20-150 | 7.55 | 7.57 | | 74.73 |
| 3W100N43 | 5.38 | 5.36 | 5.37 | 63.91 | 6W43-150 | 7.74 | 7.76 | | 75.18 |
| 5W175N12 | 6.45 | 6.42 | | 71.06 | 6W5-20 | 7.64 | 7.66 | | 74.50 |
| 5W175N50 | 6.35 | 6.38 | | 71.20 | 6W149-400 | 8.02 | 8.02 | | 76.60 |
| 6W5N12 | 6.51 | 6.50 | | 73.59 | 6W50-400 | 7.40 | 7.40 | | 74.72 |
| 6W5N50 | 6.78 | 6.78 | | 73.87 | 6W20-400 | 7.24 | 7.24 | | 74.07 |
| 3W100-20 | 6.40 | 6.42 | | 64.81 | 6W5-400 | 7.22 | 7.22 | | 73.86 |
| 3W5-20 | 6.54 | 6.54 | | 63.67 | 6E5-400 | 7.35 | 7.37 | | 73.85 |
| 1W100-20 | 6.96 | 6.96 | | 5[illegible].51 | 6E20-400 | 7.05 | 7.05 | | 73.41 |
| 1W100-150 | 7.62 | 7.62 | | 59.16 | 6E50-400 | 7.00 | 6.99 | | 73.05 |
| 2W100-150 | 7.10 | 7.10 | | 62.05 | 6E100-400 | 6.49 | 6.58 | | 73.21 |
| 3E20-150 | 6.98 | 6.98 | | 63.36 | 5W175-400 | 6.16 | 6.20 | | 71.07 |
| 3E5-150 | 7.02 | 7.02 | | 63.66 | 5W100-400 | 6.28 | 6.28 | | 70.25 |
| 3W5-150 | 7.06 | | | 63.87 | 5W20-400 | 6.28 | 6.28 | | 69.13 |
| 3W20-150 | 6.85 | 6.85 | | 63.89 | 5W5-400 | 6.37 | 6.37 | | 69.05 |
| 3W100-150 | 6.67 | 6.67 | | 64.94 | 5E5-400 | 6.40 | 6.40 | | 68.97 |
| 4W100-150 | 5.28 | 5.28 | 5.33 | 67.07 | 5E20-400 | 6.17 | 6.18 | | 68.60 |
| 5W175-150 | 6.59 | 6.59 | | 71.50 | 4W100-400 | 6.18 | 6.18 | | 67.53 |
| 5W175-20 | 7.51 | 7.51 | | 72.17 | 4W20-400 | 6.10 | 6.10 | | 66.41 |

Table 43. Continued

| Location | Water Table Depth (ft) |  |  | Elev.* Top of Pipe | Location | Water Table Depth (ft) |  |  | Elev.* Top of Pipe |
|---|---|---|---|---|---|---|---|---|---|
|  | 12 | 9 | 6 |  |  | 12 | 9 | 6 |  |
| 4W5-400 | 6.12 | 6.12 |  | 66.25 | 1W5-400 |  | 7.14 |  | 57.11 |
| 4E5-400 | 6.11 | 6.11 |  | 66.08 | 1W100-650 | 7.84 | 7.84 |  | 58.85 |
| 4E20-400 | 6.02 | 6.02 | 6.02 | 65.73 | 2W100-650 | 7.04 | 7.04 |  | 61.00 |
| 3W100-400 | 7.12 | 7.12 |  | 65.24 | 3E20-650 | 7.32 | 7.33 |  | 63.05 |
| 3W50-400 | 7.46 | 7.46 |  | 64.65 | 3E5-650 | 7.34 | 7.36 |  | 62.66 |
| 3W20-400 | 7.43 | 7.43 |  | 64.04 | 3W5-650 | 7.30 | 7.33 |  | 62.81 |
| 3W5-400 | 7.53 | 7.52 |  | 63.80 | 3W20-650 | 7.23 | 7.24 |  | 63.05 |
| 3E5-400 | 7.53 | 7.53 |  | 63.62 | 3W100-650 | 7.45 | 7.46 |  | 64.66 |
| 3E20-400 | 7.28 | 7.29 |  | 63.14 | 4W100-650 |  | 7.78 |  | 68.59 |
| 3E50-400 | 7.22 | 7.23 |  | 62.68 | 5W175-650 | 7.70 |  |  | 72.42 |
| 2W100-400 | 7.00 | 7.01 |  | 61.85 | 6E50-650 | 8.44 | 8.42 |  | 74.22 |
| 2W20-400 | 6.97 | 6.97 |  | 60.47 | 6E20-650 | 8.68 | 8.67 |  | 74.75 |
| 2W5-400 | 6.95 | 6.96 |  | 60.24 | 6E5-650 | 8.88 | 8.89 |  | 75.11 |
| 2E5-400 | 6.98 | 6.97 |  | 60.09 | 6W5-650 | 8.95 | 8.95 |  | 75.28 |
| 2E20-400 | 6.90 | 6.89 |  | 59.82 | 6W20-650 | 8.92 | 8.93 |  | 75.44 |
| 1W100-400 | 6.90 | 6.91 |  | 58.37 | 6W50-650 | 9.03 | 9.03 |  | 75.82 |
| 1W20-400 | 7.20 | 7.20 |  | 57.37 | 6W150-650 | 9.48 |  |  | 77.23 |

*Elevation above mean sea level is value plus 5200 feet.

Table 44. Electrical conductivity of the soil solution ($EC_s$) as calculated from average values of electrical conductivity of saturation extract ($EC_e$), soil water content by weight at saturation ($W_e$), and from field water content by weight (W), which was obtained from the average volumetric moisture content (θ) of each layer and from bulk density determinations.

| | Soil Depth Increment (ft) | $EC_e$ (mmho/cm) | $W_e$ | θ | W | $EC_s$ (mmho/cm) |
|---|---|---|---|---|---|---|
| June 22 | | | | | | |
| Block 3 | 0-1 | 2.18 | 38.9 | .224 | .157 | 5.40 |
| | 1-2 | 2.07 | 37.8 | .265 | .185 | 4.23 |
| | 2-3 | 2.28 | 37.6 | .281 | .197 | 4.35 |
| | 3-4 | 2.78 | 37.1 | .325 | .227 | 4.55 |
| | 4-5 | 2.73 | 41.1 | .345 | .241 | 4.65 |
| | 5-6 | 2.86 | 54.0 | .409 | .286 | 5.40 |
| Block 5 | 0-1 | 1.47 | 38.5 | .187 | .120 | 4.71 |
| | 1-2 | 1.56 | 29.9 | .235 | .151 | 3.09 |
| | 2-3 | 1.78 | 25.8 | .244 | .156 | 2.94 |
| | 3-4 | 1.75 | 32.5 | .275 | .176 | 3.23 |
| | 4-5 | 1.66 | 39.8 | .327 | .210 | 3.14 |
| | 5-6 | 1.80 | 38.3 | .379 | .243 | 2.84 |
| Block 6 | 0-1 | 2.31 | 37.0 | .203 | .130 | 6.57 |
| | 1-2 | 4.07 | 41.8 | .279 | .179 | 9.50 |
| | 2-3 | 4.82 | 42.5 | .303 | .194 | 10.57 |
| | 3-4 | 3.96 | 35.6 | .363 | .233 | 6.02 |
| | 4-5 | 3.41 | 33.4 | .405 | .260 | 4.38 |
| | 5-6 | 2.80 | 36.5 | .411 | .264 | 3.87 |
| Block 7 | 0-1 | 3.15 | 34.3 | .212 | .137 | 7.88 |
| | 1-2 | 3.69 | 35.7 | .246 | .159 | 8.28 |
| | 2-3 | 2.91 | 44.0 | .292 | .189 | 6.78 |
| | 3-4 | 2.74 | 34.6 | .360 | .232 | 4.09 |
| | 4-5 | 2.79 | 30.3 | .409 | .264 | 3.20 |
| | 5-6 | 1.78 | 36.5 | .409 | .264 | 2.46 |
| August 3 | | | | | | |
| Block 3 | 0-1 | 2.17 | 35.3 | .303 | .212 | 3.62 |
| | 1-2 | 1.96 | 36.5 | .308 | .216 | 3.31 |
| | 2-3 | 2.64 | 35.3 | .305 | .213 | 4.37 |
| | 3-4 | 2.36 | 34.0 | .328 | .229 | 3.50 |
| | 4-5 | 2.90 | 36.0 | .401 | .280 | 3.73 |

Table 44. Continued

| | Soil Depth Increment (ft) | $EC_e$ (mmho/cm) | $W_e$ | $\theta$ | W | $EC_s$ (mmho/cm) |
|---|---|---|---|---|---|---|
| Block 5 | 0-1 | 2.06 | 32.5 | .248 | .159 | 4.21 |
| | 1-2 | 2.10 | 33.9 | .269 | .172 | 4.14 |
| | 2-3 | 4.15 | 30.0 | .269 | .172 | 7.24 |
| | 3-4 | 3.02 | 29.1 | .301 | .193 | 4.55 |
| | 4-5 | 2.98 | 29.4 | .377 | .242 | 3.62 |
| Block 6 | 0-1 | 2.49 | 34.7 | .278 | .178 | 4.85 |
| | 1-2 | 3.60 | 39.3 | .319 | .204 | 6.94 |
| | 2-3 | 4.86 | 41.3 | .350 | .224 | 8.95 |
| | 3-4 | 3.51 | 30.8 | .399 | .256 | 4.22 |
| | 4-5 | 3.61 | 30.9 | .411 | .264 | 4.23 |
| Block 7 | 0-1 | 4.25 | 34.8 | .204 | .132 | 11.20 |
| | 1-2 | 3.29 | 32.5 | .260 | .168 | 6.36 |
| | 2-3 | 3.26 | 42.5 | .346 | .223 | 6.21 |
| | 3-4 | 3.10 | 35.6 | .392 | .253 | 4.36 |
| | 4-5 | 2.81 | 26.5 | .410 | .265 | 2.81 |
| September 9 | | | | | | |
| Block 3 | 0-1 | 1.62 | 43.8 | .331 | .232 | 3.06 |
| | 1-2 | 1.48 | 41.0 | .325 | .228 | 2.66 |
| | 2-3 | 2.26 | 42.8 | .327 | .229 | 4.22 |
| | 3-4 | 2.74 | 36.4 | .355 | .248 | 4.02 |
| | 4-5 | 2.60 | 42.1 | .414 | .289 | 3.79 |
| Block 5 | 0-1 | 1.38 | 44.6 | .273 | .176 | 3.50 |
| | 1-2 | 1.19 | 33.4 | .284 | .182 | 2.18 |
| | 2-3 | 1.65 | 35.9 | .283 | .182 | 3.26 |
| | 3-4 | 2.22 | 34.5 | .318 | .204 | 3.76 |
| | 4-5 | 2.31 | 36.6 | .382 | .245 | 3.45 |
| Block 6 | 0-1 | 3.09 | 43.7 | .268 | .172 | 7.85 |
| | 1-2 | 4.10 | 51.5 | .334 | .214 | 9.86 |
| | 2-3 | 5.36 | 44.2 | .386 | .248 | 9.55 |
| | 3-4 | 5.22 | 38.6 | .400 | .256 | 7.87 |
| | 4-5 | 3.70 | 37.8 | .411 | .264 | 5.30 |
| Block 7 | 0-1 | 3.15 | 45.1 | .256 | .165 | 8.61 |
| | 1-2 | 3.35 | 51.0 | .297 | .192 | 8.90 |
| | 2-3 | 3.12 | 46.0 | .356 | .230 | 6.25 |
| | 3-4 | 3.18 | 37.8 | .383 | .247 | 4.87 |
| | 4-5 | 2.24 | 30.1 | .406 | .262 | 2.57 |

Table 45. Typical composition of salts in Hullinger farm soils.

| Depth (in) | pH | mmhos $EC_e$ | Water-Soluble meq/1 Ca | Mg | Na | K | Cl | meq/100g $SO_4$ | Sat. % SP |
|---|---|---|---|---|---|---|---|---|---|
| 0-6 | 7.5 | 1.7 | 12.5 | 5.7 | 1.4 | .56 | <.01 | .45 | 38.2 |
| 6-12 | 7.5 | 2.0 | 20.5 | 6.3 | 1.6 | .32 | <.01 | 1.11 | 31.1 |
| 12-18 | 7.6 | 3.0 | 27.5 | 16.9 | 1.6 | .28 | <.01 | 1.32 | 48.7 |
| 18-24 | 7.7 | 3.3 | 27.5 | 23.3 | 3.5 | .16 | <.01 | 3.74 | 36.3 |
| 24-30 | 7.7 | 3.2 | 28.0 | 22.2 | 3.7 | .13 | .04 | 2.12 | 31.8 |
| 30-36 | 7.7 | 3.2 | 27.5 | 22.3 | 3.7 | .14 | .02 | 4.11 | 41.2 |
| 36-42 | 7.8 | 3.4 | 28.0 | 24.7 | 3.7 | .16 | <.01 | 2.23 | 36.1 |
| 42-48 | 7.6 | 3.2 | 28.0 | 21.6 | 3.7 | .16 | <.01 | 2.30 | 30.6 |
| 48-54 | 7.4 | 3.4 | 32.0 | 19.5 | 3.8 | .22 | <.01 | 1.34 | 29.5 |
| 54-60 | 7.4 | 2.8 | 30.0 | 12.6 | 2.7 | .20 | <.01 | 1.22 | 32.5 |

Table 46. Typical composition of groundwater samples from observation holes.

| Location | Depth (ft) | Ca meq/l | Mg meq/l | Na meq/l | Cl meq/l | $SO_4$ meq/l | $NO_3$ ppm | EC mmho/cm |
|---|---|---|---|---|---|---|---|---|
| 2W99-19 | 10 | 9.5 | 6.4 | .9 | .23 | 12.3 | .31 | 1248 |
| " | 15 | 9.7 | 6.4 | .9 | --- | ---- | -- | 1265 |
| " | 20 | 9.5 | 6.4 | .9 | .23 | 10.3 | .34 | 1248 |
| " | 25 | 9.5 | 6.5 | .9 | --- | ---- | --- | 1241 |
| " | 30 | 10.2 | 6.5 | .9 | --- | ---- | --- | 1328 |
| 1E31[illegible]-400 | 15 | 11.3 | 8.0 | 1.2 | --- | ---- | --- | 1525 |
| " | 20 | 10.2 | 8.1 | 1.1 | --- | ---- | --- | 1462 |
| " | 25 | 10.8 | 8.0 | 1.2 | --- | ---- | --- | 1482 |
| " | 30 | 11.4 | 8.1 | 1.1 | --- | ---- | --- | 1462 |
| 1E54-728 | 10 | 16.0 | 12.0 | 2.5 | --- | ---- | --- | 2135 |
| " | 15 | 15.3 | 12.1 | 2.6 | --- | ---- | --- | 1977 |
| " | 20 | 16.2 | 12.4 | 2.5 | --- | ---- | --- | 1977 |
| " | 25 | 15.9 | 12.5 | 2.5 | --- | ---- | --- | 2068 |
| 4W10-745 | 10 | 9.2 | 8.9 | 1.2 | .23 | 13.8 | .47 | 1450 |
| " | 15 | 9.9 | 9.0 | 1.2 | --- | ---- | --- | 1368 |
| " | 20 | 9.9 | 8.9 | 1.2 | .23 | 12.8 | .53 | 1450 |
| " | 25 | 9.8 | 8.8 | 1.2 | --- | ---- | --- | 1442 |
| " | 30 | 8.7 | 11.0 | 2.3 | --- | ---- | --- | 1570 |
| 6W121-738 | 15 | 9.9 | 7.8 | .9 | --- | ---- | --- | 1404 |
| " | 20 | 9.3 | 7.5 | .9 | --- | ---- | --- | 1318 |
| " | 25 | 9.8 | 7.6 | 1.0 | --- | ---- | --- | 1375 |
| " | 30 | 10.1 | 7.7 | 1.0 | --- | ---- | --- | 1404 |
| 6W147-331 | 10 | 8.1 | 8.9 | .9 | --- | ---- | --- | 1235 |
| " | 15 | 9.5 | 8.7 | .8 | --- | ---- | --- | 1397 |
| " | 20 | 9.9 | 8.6 | .8 | --- | ---- | --- | 1375 |
| " | 25 | 9.8 | 8.4 | .8 | --- | ---- | --- | 1334 |
| " | 30 | 9.2 | 8.4 | .8 | --- | ---- | --- | 1334 |
| " | 34 | 10.2 | 8.4 | .8 | --- | ---- | --- | 1351 |
| 5W102-19 | 10 | 11.0 | 7.0 | 1.0 | --- | ---- | --- | 1435 |
| " | 15 | 11.2 | 7.4 | .9 | --- | ---- | --- | 1435 |
| " | 20 | 10.6 | 7.3 | .9 | --- | ---- | --- | 1361 |
| " | 25 | 10.6 | 7.2 | 1.1 | --- | ---- | --- | 1361 |
| " | 30 | 11.2 | 7.1 | 1.1 | --- | ---- | --- | 1375 |
| " | 35 | 12.4 | 7.0 | .9 | --- | ---- | --- | 1474 |

Table 47. Field measurements of EC (µmhos/cm) of groundwater samples from observation holes.

| Date | Depth of Sample* (ft) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| 5W102-19 | | | | | | | |
| May 19 | 1280(7) | 1260 | 1250 | 1260 | 1220 | 1230 | 1660(33) |
| June 5 | 1440(6) | 1370 | 1350 | 1320 | 1310 | 1390 | 1360(33) |
| June 18 | 1270(6) | 1220 | 1290 | 1370 | 1290 | 1280 | 1320(33) |
| July 13 | 1350(7) | 1370 | 1330 | 1280 | 1300 | 1300 | 1290(33) |
| Aug. 24 | 1200(6) | 1210 | 1170 | 1180 | 1170 | 1140 | 1170(34) |
| Sept. 1 | 1370(7) | 1340 | 1320 | 1240 | 1230 | 1220 | 1210(34) |
| Sept. 9 | 1340(7) | 1320 | 1250 | 1210 | 1200 | 1190 | 1240(34) |
| Sept.16 | 1230(7) | 1240 | 1210 | 1200 | 1160 | 1160 | 1190(34) |
| 2W99-19 | | | | | | | |
| May 18 | | 1280 | 1250 | 1310 | 1300 | 1260 | 1260(31) |
| June 3 | 1340(6) | 1300 | 1300 | 1290 | 1300 | 1300 | |
| June 17 | 1290(6) | 1260 | 1260 | 1320 | 1300 | 1290 | 1280(31) |
| July 12 | 1250(6) | 1200 | 1240 | 1240 | 1220 | 1240 | 1210(31) |
| Aug. 24 | 1250(7) | 1180 | 1230 | 1160 | 1210 | 1140 | 1170(31) |
| Aug. 31 | 1370(6) | 1410 | 1350 | 1280 | 1230 | 1240 | 1230(32) |
| Sept. 9 | 1110(7) | 1170 | 1180 | 1180 | 1170 | 1150 | 1170(32) |
| Sept.16 | 1220(8) | 1190 | 1180 | 1170 | 1150 | 1170 | 1160(32) |
| 1E358-400 | | | | | | | |
| May 18 | | 1490(11) | 1580 | 1600 | 1600 | 1600 | |
| June 5 | | 1440(11) | 1610 | 1610 | 1610 | 1630(28) | |
| June 18 | | 1580(11) | 1590 | 1550 | 1580 | 1570(28) | |
| July 12 | | 1150(11) | 1110 | 1490 | 1490 | 1480(28) | |
| Aug. 24 | | 1330(12) | 1370 | 1410 | 1470 | 1410(29) | |
| Sept. 1 | | 1430(12) | 1410 | 1400 | 1390 | 1450(29) | |
| Sept. 9 | | 1630(12) | 1660 | 1560 | 1590 | 1700(29) | |
| Sept.16 | | 1350(12) | 1300 | 1320 | 1310 | 1460(29) | |
| Co. "B" | | | | | | | |
| May 18 | | 1650(11) | 1680 | 1490 | 1650 | 1960 | |
| June 5 | | 1860 | 1890 | 1850 | 1860 | 2160 | |
| June 18 | 1470(7) | 2020 | 1910 | 1830 | 1870 | 1960 | |
| July 12 | | 1830 | 1710 | 1670 | 1680 | 2000 | |
| Aug. 21 | | 1720(12) | 1690 | 1690 | | | |
| Aug. 24 | | | | | 1510 | 1870 | |
| Sept. 1 | | 1640 | 1640 | 1580 | 1590 | 1930 | |
| Sept. 9 | | 1640(11) | 1600 | 1550 | 1540 | 1940 | |
| Sept. 16 | | 1530(11) | 1530 | 1460 | 1440 | 1500 | |

Table 47. Continued

| Date | Depth of Sample* (ft)<br>5 | 10 | 15 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|---|---|
| 1E54-728 | | | | | | | |
| May 18 | | 2250 | 2250 | 2340 | 2430 | | |
| June 5 | 2430(7) | 2310 | 2280 | 2290 | 2350 | | |
| June 18 | 2240(7) | 2270 | 2230 | 2240 | 2270 | | |
| July 12 | 2210(8) | 2160 | 2250 | 2140 | 2270 | | |
| Aug. 24 | 2100(7) | 1970 | 1970 | 2020 | 2100 | | |
| Sept. 1 | 1850(7) | 1790 | 1800 | 1840 | 1900 | | |
| Sept. 9 | 1750(8) | 1760 | 1740 | 1750 | 1840 | | |
| Sept.16 | 1760(8) | 1760 | 1760 | 1800 | 1850 | | |
| 4W10-745 | | | | | | | |
| May 19 | | 1670 | 1600 | 1600 | 1500 | 1630 | |
| June 4 | | 1860 | 1760 | 1720 | 1610 | 1640 | |
| June 18 | 1570(7) | 1580 | 1570 | 1540 | 1460 | 1600 | |
| July 12 | 1530(8) | 1510 | 1500 | 1530 | 1470 | 1620 | |
| Aug. 24 | 1400(8) | 1410 | 1380 | 1300 | 1370 | 1480 | |
| Sept. 1 | 1490(8) | 1400 | 1420 | 1450 | 1400 | 1560 | |
| Sept. 9 | 1410(8) | 1380 | 1370 | 1390 | 1320 | 1370 | |
| Sept.16 | 1370(8) | 1360 | 1360 | 1350 | 1360 | 1370 | |
| 6W121-738 | | | | | | | |
| May 19 | | 1550 | 1540 | 1550 | 1560 | 1610 | |
| June 4 | | 1600 | 1520 | 1530 | 1520 | 1560 | |
| June 18 | | 1440 | 1430 | 1410 | 1440 | 1420 | |
| July 12 | | 1430 | 1370 | 1380 | 1360 | 1370 | |
| Aug. 17 | | 1360 | 1340 | 1350 | 1370 | 1370 | 1490(31) |
| Aug. 25 | | 1405 | | | | | |
| Sept. 1 | | 1370 | 1340 | 1310 | 1370 | 1380 | 1440(31) |
| Sept. 9 | | 1350 | 1330 | 1330 | 1330 | 1320 | 1370(31) |
| Sept.16 | | 1260 | 1250 | 1250 | 1240 | 1260 | 1350(31) |
| 6W147-331 | | | | | | | |
| May 19 | | 1440 | 1400 | 1410 | 1420 | 1410 | 1420 |
| June 4 | 1520(7) | 1460 | 1450 | 1450 | 1460 | 1440 | 1440(33) |
| June 18 | 1390(7) | 1350 | 1360 | 1370 | 1350 | 1350 | 1360(33) |
| July 13 | 1460(7) | 1450 | 1430 | 1440 | 1440 | 1430 | 1440(33) |
| Aug. 19 | | 1430 | 1360 | 1350 | 1370 | | |
| Sept. 1 | 1410(7) | 1350 | 1340 | 1320 | 1360 | 1350 | 1350(34) |
| Sept. 9 | 1350(8) | 1310 | 1290 | 1320 | 1350 | 1370 | 1340(34) |

*Numbers in parentheses indicate actual depth at which sample was taken if different from nominal depth indicated in column heading.

Table 48. Field measurements of EC (μmhos/cm) of groundwater samples from selected piezometers.

| | Piezometer Depth (ft) | | | | Piezometer Depth (ft) | | |
|---|---|---|---|---|---|---|---|
| Date | 12 | 9 | 6 | Date | 12 | 9 | 6 |
| 6E5-400 | | | | 5W175-400 | | | |
| Aug. 20 | 450 | 400 | 1460 | Aug. 20 | 120 | 160 | 1280 |
| Aug. 23 | 960 | 1670 | 1640 | Aug. 23 | 1200 | 1170 | 1500 |
| Aug. 25 | 1360 | 1780 | 1660 | Aug. 25 | 1220 | 1350 | 1590 |
| Aug. 30 | 1300 | 1660 | 1600 | Aug. 30 | 1140 | 1220 | 1580 |
| Sept. 8 | 1230 | 1650 | 1290 | Sept. 8 | 1300 | 1210 | 1470 |
| Sept. 15 | 1160 | 1630 | 1400 | Sept. 15 | 1110 | 1160 | 1420 |
| Sept. 28 | 1120 | 1450 | 1460 | Sept. 28 | 1090 | 1060 | 1660 |
| 6E20-400 | | | | 5W100-400 | | | |
| Aug. 20 | 650 | 990 | 1320 | Aug. 20 | 880 | 580 | 1210 |
| Aug. 23 | 1270 | 1630 | 1670 | Aug. 23 | 1280 | 1310 | 1570 |
| Aug. 25 | 1410 | 1780 | 1730 | Aug. 25 | 1320 | 1480 | 1650 |
| Aug. 30 | 1350 | 1810 | 1760 | Aug. 30 | 1370 | 1390 | 1570 |
| Sept. 8 | 1260 | 1780 | 1650 | Sept. 8 | 1230 | 1310 | 1560 |
| Sept. 15 | 1240 | 1690 | 1700 | Sept. 15 | 1320 | 1300 | 1470 |
| Sept. 28 | 1200 | 1610 | 1380 | Sept. 28 | 1220 | 1270 | 1390 |
| 6E50-400 | | | | 5W20-400 | | | |
| Aug. 20 | 260 | 970 | 1220 | Aug. 20 | 680 | 630 | 1200 |
| Aug. 23 | 1140 | 1500 | 1640 | Aug. 23 | 1170 | 1430 | 1500 |
| Aug. 25 | 1110 | 1550 | 1630 | Aug. 25 | 1220 | 1530 | 1670 |
| Aug. 30 | 1180 | 1560 | 1560 | Aug. 30 | 1380 | 1470 | 1640 |
| Sept. 8 | 1190 | 1470 | 1270 | Sept. 8 | 1320 | 1440 | 1590 |
| Sept. 15 | 1100 | 1500 | 1540 | Sept. 15 | 1230 | 1390 | 1500 |
| Sept. 28 | 1040 | 1310 | 1730 | Sept. 28 | 1140 | 1290 | 1420 |
| 6E100-400 | | | | 5W5-400 | | | |
| Aug. 20 | 1020 | 1020 | 1350 | Aug. 20 | 290 | 960 | 1240 |
| Aug. 23 | 1330 | 1570 | 1680 | Aug. 23 | 860 | 1460 | 1610 |
| Aug. 25 | 1230 | 1590 | 1750 | Aug. 25 | 1270 | 1520 | 1700 |
| Aug. 30 | 1420 | 1500 | 1680 | Aug. 30 | 1160 | 1500 | 1630 |
| Sept. 8 | 1360 | 1440 | 1690 | Sept. 8 | 1100 | 1400 | 1540 |
| Sept. 15 | 1350 | 1450 | 1590 | Sept. 15 | 1100 | 1400 | 1500 |
| Sept. 28 | 1260 | 1330 | 1500 | Sept. 28 | 1020 | 1360 | 1370 |

Table 48. Continued

| Date | Piezometer Depth (ft) | | |
|---|---|---|---|
| | 12 | 9 | 6 |
| 5E5-400 | | | |
| Aug. 18 | 850 | 1110 | 1260 |
| Aug. 23 | 660 | 1240 | 1460 |
| Aug. 25 | 1040 | 1430 | 1470 |
| Aug. 30 | 1180 | 1450 | 1470 |
| Sept. 8 | 1110 | 1350 | 1430 |
| Sept. 15 | 1140 | 1320 | 1350 |
| Sept. 28 | 1060 | 1180 | 1300 |
| 5E20-400 | | | |
| Aug. 18 | 700 | 750 | 1160 |
| Aug. 23 | 1113 | 1340 | 1450 |
| Aug. 25 | 1300 | 1400 | 1550 |
| Aug. 30 | 1230 | 1360 | 1470 |
| Sept. 8 | 1230 | 1400 | 1480 |
| Sept. 15 | 1210 | 1310 | 1410 |
| Sept. 28 | 1080 | 1230 | 1280 |
| 4W100-400 | | | |
| Aug. 18 | 380 | 970 | 1220 |
| Aug. 23 | 1140 | 1430 | 1390 |
| Aug. 25 | 1320 | 1440 | 1470 |
| Aug. 30 | 1160 | 1440 | 1470 |
| Sept. 8 | 1150 | 1380 | 1330 |
| Sept. 15 | 1110 | 1350 | 1370 |
| Sept. 28 | 980 | 1270 | 1290 |
| 4W20-400 | | | |
| Aug. 18 | 800 | 890 | 1190 |
| Aug. 23 | 1280 | 1310 | 1470 |
| Aug. 25 | 1300 | 1350 | 1490 |
| Aug. 30 | 1320 | 1440 | 1490 |
| Sept. 8 | 1160 | 1260 | 1450 |
| Sept. 15 | 1250 | 1360 | 1390 |
| Sept. 28 | 1060 | 1100 | 1480 |
| 4W5-400 | | | |
| Aug. 18 | 930 | 1060 | 1150 |
| Aug. 23 | 1330 | 1340 | 1520 |
| Aug. 25 | 1320 | 1340 | 1500 |
| Aug. 30 | 1340 | 1370 | 1540 |
| Sept. 8 | 1340 | 1440 | 1530 |
| Sept. 15 | 1250 | 1340 | 1390 |
| Sept. 28 | 1100 | 1180 | 1400 |
| 4E5-400 | | | |
| Aug. 18 | 970 | 370 | 1060 |
| Aug. 23 | 1280 | 1240 | 1370 |
| Aug. 25 | 1280 | 1350 | 1430 |
| Aug. 30 | 1340 | 1420 | 1440 |
| Sept. 8 | 1390 | 1440 | 1360 |
| Sept. 15 | 1220 | 1190 | 1140 |
| Sept. 28 | 1060 | 1040 | 1140 |
| 4E20-400 | | | |
| Aug. 18 | 930 | 690 | 1280 |
| Aug. 23 | 1240 | 1390 | 1460 |
| Aug. 25 | 1100 | 1390 | 1410 |
| Aug. 30 | 1260 | 1640 | 1470 |
| Sept. 8 | 1120 | 1440 | 1440 |
| Sept. 15 | 950 | 1250 | 1320 |
| Sept. 28 | 990 | 1100 | 1440 |
| 3W100-400 | | | |
| Aug. 18 | 440 | 1240 | 1650 |
| 3W20-400 | | | |
| Aug. 18 | 1030 | 1830 | 870 |
| 3W5-400 | | | |
| Aug. 18 | 1530 | 470 | 1490 |

Table 48. Continued

| Date | Piezometer Depth (ft) | | | Date | Piezometer Depth (ft) | | |
|---|---|---|---|---|---|---|---|
| | 12 | 9 | 6 | | 12 | 9 | 6 |
| 3E5-400 | | | | | | | |
| Aug. 18 | | 860 | 1680 | | | | |
| 3E20-400 | | | | | | | |
| Aug. 18 | 1060 | 620 | 1830 | | | | |
| 3E50-400 | | | | | | | |
| Aug. 18 | 1290 | 1270 | 2070 | | | | |

Table 49. Average values of transmissability, T, hydraulic conductivity, K, specific yield, V, and $\alpha$ from constant discharge test. $\alpha = T/V$.

| Depth of Piezometer in ft. | T ($ft^2/sec$) | K (in/hr) | $\alpha$ ($ft^2/sec$) | V (%) |
|---|---|---|---|---|
| 6 | $9.48(10^{-3})$ | 13.20 | $4.6\ (10^{-2})$ | 20.1 |
| 9 | $9.53(10^{-3})$ | 13.30 | $4.05(10^{-2})$ | 23.5 |
| 12 | $10.65(10^{-3})$ | 15.10 | $3.88(10^{-2})$ | 27.4 |

Table 50. Values of hydraulic conductivity, K, by auger-hole method and corresponding specific yield, V, from Figure 7 of Dumm (1968).

| Location | 1st stage test | | 2nd stage test | |
|---|---|---|---|---|
| | K(in/hr) | V (%) | K(in/hr) | V (%) |
| 6E40-150 | 3.42 | 16.0 | 6.70 | 20.0 |
| 6E50-270 | 6.35 | 19.0 | 5.00 | 18.0 |
| 6W50-410 | 10.05 | 22.0 | 4.95 | 18.0 |
| 6E40-500 | 4.17 | 17.0 | 3.35 | 16.0 |
| 6W50-660 | 3.12 | 15.6 | 7.90 | 20.0 |

Table 51. Soil properties used for computations made. Mesa sandy clay loam soil.

| Water Content $\theta$ | Hydraulic Conductivity, K (cm/hr) | Pressure Head, h (cm) |
|---|---|---|
| .00 | 1.0 $(10^{-9})$ | -2 $(10^{6})$ |
| .01 | 2.0 $(10^{-9})$ | -1.3 $(10^{6})$ |
| .02 | 3.4 $(10^{-9})$ | -8.5 $(10^{5})$ |
| .03 | 1.0 $(10^{-8})$ | -4.2 $(10^{5})$ |
| .04 | 1.7 $(10^{-8})$ | -2.2 $(10^{5})$ |
| .05 | 3.0 $(10^{-8})$ | -1.15 $(10^{5})$ |
| .06 | 5.4 $(10^{-8})$ | -5.8 $(10^{4})$ |
| .07 | 9.2 $(10^{-8})$ | -3.0 $(10^{4})$ |
| .08 | 1.6 $(10^{-7})$ | -1.5 $(10^{4})$ |
| .09 | 2.7 $(10^{-7})$ | -1.1 $(10^{4})$ |
| .10 | 4.8 $(10^{-7})$ | -8.0 $(10^{3})$ |
| .11 | 7.5 $(10^{-7})$ | -6.2 $(10^{3})$ |
| .12 | 1.5 $(10^{-7})$ | -4.9 $(10^{3})$ |
| .13 | 2.5 $(10^{-6})$ | -4.0 $(10^{3})$ |
| .14 | 4.5 $(10^{-6})$ | -3.0 $(10^{3})$ |
| .15 | 8.7 $(10^{-6})$ | -2.35 $(10^{3})$ |
| .16 | 1.4 $(10^{-5})$ | -1.85 $(10^{3})$ |
| .17 | 2.5 $(10^{-5})$ | -1.45 $(10^{3})$ |
| .18 | 4.5 $(10^{-5})$ | -1.12 $(10^{3})$ |
| .19 | 7.5 $(10^{-5})$ | -8.7 $(10^{3})$ |
| .20 | 1.1 $(10^{-4})$ | -6.7 $(10^{2})$ |

Table 51. Continued

| Water Content $\theta$ | Hydraulic Conductivity, K (cm/hr) | Pressure Head, h (cm) |
|---|---|---|
| .21 | $1.7\ (10^{-4})$ | $-5.3\ (10^{2})$ |
| .22 | $2.7\ (10^{-4})$ | $-4.1\ (10^{2})$ |
| .23 | $4.0\ (10^{-4})$ | $-3.2\ (10^{2})$ |
| .24 | $6.1\ (10^{-4})$ | $-2.5\ (10^{2})$ |
| .25 | $9.5\ (10^{-4})$ | $-2.0\ (10^{2})$ |
| .26 | $1.5\ (10^{-3})$ | $-1.65\ (10^{2})$ |
| .27 | $2.4\ (10^{-3})$ | $-1.35\ (10^{2})$ |
| .28 | $3.5\ (10^{-3})$ | $-1.15\ (10^{2})$ |
| .29 | $5.5\ (10^{-3})$ | $-9.9\ (10)$ |
| .30 | $9.0\ (10^{-3})$ | $-8.5\ (10)$ |
| .31 | $1.4\ (10^{-2})$ | $-7.4\ (10)$ |
| .32 | $2.1\ (10^{-2})$ | $-5.5\ (10)$ |
| .33 | $2.8\ (10^{-2})$ | $-5.6\ (10)$ |
| .34 | $3.5\ (10^{-2})$ | $-4.8\ (10)$ |
| .35 | $4.6\ (10^{-2})$ | $-4.5\ (10)$ |
| .36 | $6.0\ (10^{-2})$ | $-4.1\ (10)$ |
| .37 | $7.9\ (10^{-2})$ | $-3.8\ (10)$ |
| .38 | $1.0\ (10^{-1})$ | $-3.4\ (10)$ |
| .39 | $1.3\ (10^{-1})$ | $-3.112(10)$ |
| .40 | $1.7\ (10^{-1})$ | $-2.731(10)$ |
| .41 | $2.3\ (10^{-1})$ | $-2.413(10)$ |
| .42 | $3.1\ (10^{-1})$ | $-2.096(10)$ |

Table 51. Continued

| Water Content $\theta$ | Hydraulic Conductivity, K (cm/hr) | Pressure Head, h (cm) |
|---|---|---|
| .43 | $4.1\ (10^{-1})$ | -1.715(10) |
| .44 | $5.4\ (10^{-1})$ | -1.335(10) |
| .45 | $6.9\ (10^{-1})$ | -1.016(10) |
| .46 | $8.8\ (10^{-1})$ | -6.985 |
| .47 | 1.03 | -3.175 |
| .48 | 1.30 | - .0000 |

Table 52. Root distribution (RDF), salt content (SE) for alfalfa in 1971 and initial water content for alfalfa crop 1 ($\theta_1$), crop 2 ($\theta_2$), crop 3 ($\theta_3$) versus depth used for the computations made.

| Depth (cm) | RDF | SE (mmho/cm) | $\theta_1$ | $\theta_2$ | $\theta_3$ |
|---|---|---|---|---|---|
| 0 | .0000 | .000 | .080 | .180 | .242 |
| 1 | .0280 | .475 | .085 | .180 | .2425 |
| 3 | .0560 | .505 | .090 | .181 | .2435 |
| 5 | .0560 | .5113 | .095 | .183 | .2445 |
| 8 | .0840 | .5200 | .100 | .185 | .2455 |
| 12 | .1118 | .5325 | .110 | .189 | .2465 |
| 16 | .1042 | 1.0000 | .120 | .1915 | .2475 |
| 20 | .0766 | 1.3500 | .130 | .195 | .2485 |
| 25 | .0967 | 1.7750 | .144 | .198 | .2500 |
| 30 | .0967 | 2.2000 | .155 | .202 | .2520 |
| 35 | .0637 | 2.6250 | .195 | .215 | .2600 |
| 40 | .0633 | 3.0250 | .225 | .230 | .2680 |
| 45 | .0633 | 3.4620 | .265 | .245 | .2760 |
| 55 | .0666 | 3.1750 | .267 | .244 | .2740 |
| 70 | .0344 | 2.7250 | .268 | .240 | .2675 |
| 85 | .0000 | 2.4000 | .273 | .265 | .2740 |
| 100 | .0000 | 2.1000 | .275 | .285 | .2870 |
| 115 | .0000 | 1.8000 | .285 | .301 | .3175 |
| 135 | .0000 | 1.4120 | .305 | .326 | .3780 |
| 155 | .0000 | 1.0500 | .365 | .370 | .4035 |
| 165 | .0000 | .6250 | .400 | .400 | .4140 |

Table 53. Root distribution (RDF), assumed for oats in 1970 with initial electrical conductivity (SE), and initial water content ($\theta_o$) versus depth.

| Soil Depth (cm) | RDF | SE (mmho/cm) | $\theta_o$ |
|---|---|---|---|
| 0 | .000 | .0 | .040 |
| 1 | .036 | .5 | .041 |
| 3 | .073 | .5 | .045 |
| 5 | .073 | .5 | .050 |
| 8 | .109 | .5 | .055 |
| 12 | .145 | .5 | .064 |
| 16 | .145 | 1.0 | .072 |
| 20 | .146 | 1.4 | .080 |
| 25 | .182 | 1.8 | .090 |
| 30 | .091 | 2.2 | .100 |
| 35 | .000 | 2.6 | .143 |
| 40 | .000 | 3.0 | .190 |
| 45 | .000 | 3.5 | .238 |
| 55 | .000 | 3.1 | .245 |
| 70 | .000 | 2.7 | .256 |
| 85 | .000 | 2.4 | .270 |
| 100 | .000 | 2.1 | .285 |
| 115 | .000 | 1.8 | .315 |
| 135 | .000 | 1.4 | .370 |
| 155 | .000 | 1.0 | .433 |
| 165 | .000 | .6 | .463 |

Table 54. Flux at the surface for alfalfa in 1971, evapotranspiration (ET), soil surface flux (WF), positive values are precipitation, negative values are evaporation, and salt concentration (SF) versus time.

| Time Interval hours | ET cm/hr | WF cm/hr | SF mmho/cm |
|---|---|---|---|
| | Crop 1 | | |
| 0 - 25 | $-.336\ (10^{-1})$ | $-.336\ (10^{-2})$ | .000 |
| 25 - 52 | $-.25\ (10^{-2})$ | $-.25\ (10^{-3})$ | .000 |
| 52 - 55 | -.000 | .5433 | .635 |
| 55 - 74 | $-.41\ (10^{-2})$ | $-.41\ (10^{-3})$ | .000 |
| 74 - 75 | -.000 | .20 | .000 |
| 75 - 98 | $-.43\ (10^{-2})$ | $-.43\ (10^{-3})$ | .000 |
| 98 - 122 | $-.20\ (10^{-1})$ | $-.20\ (10^{-2})$ | .000 |
| 122 - 169 | $-.175\ (10^{-1})$ | $-.175\ (10^{-2})$ | .000 |
| 169 - 193 | $-.30\ (10^{-1})$ | $-.30\ (10^{-2})$ | .000 |
| 193 - 196 | -.000 | .59 | .635 |
| 196 - 220 | $-.40\ (10^{-4})$ | $-.40\ (10^{-4})$ | .000 |
| 220 - 223 | .000 | .5233 | .635 |
| 223 - 242 | $-.50\ (10^{-3})$ | $-.50\ (10^{-4})$ | .000 |
| 242 - 290 | $-.254\ (10^{-1})$ | $-.254\ (10^{-2})$ | .000 |
| 290 - 313 | $-.139\ (10^{-1})$ | $-.139\ (10^{-2})$ | .000 |
| 313 - 337 | .000 | .1162 | .000 |
| 337 - 414 | $-.2766(10^{-1})$ | $-.2766(10^{-2})$ | .000 |
| 414 - 457 | $-.145\ (10^{-1})$ | $-.145\ (10^{-2})$ | .000 |
| 457 - 482 | $-.96\ (10^{-2})$ | $-.96\ (10^{-3})$ | .000 |
| 482 - 487 | .000 | .598 | .635 |

Table 54. Continued

| Time interval hours | ET cm/hr | WF cm/hr | SF mmho/cm |
|---|---|---|---|
| 487 - 530 | -.375 ($10^{-2}$) | -.375 ($10^{-3}$) | .000 |
| 530 - 626 | -.192 ($10^{-1}$) | -.192 ($10^{-2}$) | .000 |
| 626 - 648 | -.72 ($10^{-2}$) | -.72 ($10^{-3}$) | .000 |
| 648 - 657 | .000 | .5366 | .635 |
| 657 - 672 | -.193 ($10^{-1}$) | -.193 ($10^{-2}$) | .000 |
| 672 - 698 | -.326 ($10^{-1}$) | -.326 ($10^{-2}$) | .000 |
| 698 - 722 | -.154 ($10^{-1}$) | -.154 ($10^{-2}$) | .000 |
| 722 - 793 | -.241 ($10^{-2}$) | -.241 ($10^{-2}$) | .000 |
| 793 - 868 | -.224 ($10^{-1}$) | -.224 ($10^{-2}$) | .000 |
| 868 - 919 | -.320 ($10^{-2}$) | -.320 ($10^{-2}$) | .000 |
| 919 - 920 | .000 | .030 | .000 |
| 920 - 938 | -.30 ($10^{-1}$) | -.30 ($10^{-2}$) | .000 |
| | Crop 2 | | |
| 0 - 22 | -.246 ($10^{-1}$) | -.246 ($10^{-2}$) | .000 |
| 22 - 48 | -.181 ($10^{-1}$) | -.181 ($10^{-2}$) | .000 |
| 48 - 73 | -.146 ($10^{-1}$) | -.146 ($10^{-2}$) | .000 |
| 73 - 96 | .000 | .565 ($10^{-2}$) | .000 |
| 96 - 120 | -.134 ($10^{-1}$) | -.134 ($10^{-2}$) | .000 |
| 120 - 157 | -.141 ($10^{-1}$) | -.141 ($10^{-2}$) | .000 |
| 157 - 169 | .000 | .5041 | .635 |
| 169 - 187 | .000 | .015 | .000 |
| 187 - 216 | -.177 ($10^{-1}$) | -.177 ($10^{-2}$) | .000 |

Table 54. Continued

| Time Interval hours | ET cm/hr | WF cm/hr | SF mmho/cm |
|---|---|---|---|
| 216 - 241 | -.249 $(10^{-1})$ | -.249 $(10^{-2})$ | .000 |
| 241 - 288 | -.30 $(10^{-1})$ | -.30 $(10^{-2})$ | .000 |
| 288 - 408 | -.275 $(10^{-1})$ | -.275 $(10^{-2})$ | .000 |
| 408 - 417 | -.749 $(10^{-1})$ | -.749 $(10^{-2})$ | .000 |
| 417 - 429 | .000 | .5608 | .635 |
| 429 - 456 | -.281 $(10^{-1})$ | -.281 $(10^{-2})$ | .000 |
| 456 - 504 | -.383 $(10^{-1})$ | -.383 $(10^{-2})$ | .000 |
| 504 - 528 | -.289 $(10^{-1})$ | -.289 $(10^{-2})$ | .000 |
| 528 - 576 | -.241 $(10^{-1})$ | -.241 $(10^{-2})$ | .000 |
| 576 - 626 | -.251 $(10^{-1})$ | -.251 $(10^{-2})$ | .000 |
| 626 - 648 | .000 | .363 $(10^{-2})$ | .000 |
| 648 - 671 | .000 | .435 $(10^{-2})$ | .000 |
| 671 - 683 | .000 | .6033 | 1.775 |
| 683 - 719 | .000 | .000 | .000 |
| 719 - 769 | -.234 $(10^{-1})$ | -.234 $(10^{-2})$ | .000 |
| 769 - 816 | -.259 $(10^{-1})$ | -.259 $(10^{-2})$ | .000 |
| 816 - 817 | .000 | .03 | .000 |
| 817 - 865 | -.264 $(10^{-1})$ | -.264 $(10^{-2})$ | .000 |
| 865 - 889 | -.323 $(10^{-1})$ | -.323 $(10^{-2})$ | .000 |
| 889 - 893 | .000 | .6425 | .635 |
| 893 - 912 | -.456 $(10^{-1})$ | -.456 $(10^{-2})$ | .000 |
| 912 - 963 | -.277 $(10^{-1})$ | -.277 $(10^{-2})$ | .000 |

Table 54. Continued

| Time Interval hours | ET cm/hr | WF cm/hr | SF mmho/cm |
|---|---|---|---|
| 963 - 1005 | -.226 $(10^{-1})$ | -.226 $(10^{-2})$ | .000 |
| | Crop 3 | | |
| 0 - 24 | -.625 $(10^{-2})$ | -.625 $(10^{-3})$ | .000 |
| 24 - 48 | -.127 $(10^{-1})$ | -.127 $(10^{-2})$ | .000 |
| 48 - 144 | -.142 $(10^{-1})$ | -.142 $(10^{-2})$ | .000 |
| 144 - 240 | -.243 $(10^{-1})$ | -.243 $(10^{-2})$ | .000 |
| 240 - 312 | -.30 $(10^{-1})$ | -.30 $(10^{-2})$ | .000 |
| 312 - 328 | .000 | .6362 | 1.0920 |
| 328 - 336 | .000 | .000 | .000 |
| 336 - 360 | -.211 $(10^{-1})$ | -.211 $(10^{-2})$ | .000 |
| 360 - 480 | -.187 $(10^{-1})$ | -.187 $(10^{-2})$ | .000 |
| 480 - 552 | -.135 $(10^{-1})$ | -.135 $(10^{-2})$ | .000 |
| 552 - 612 | -.219 $(10^{-1})$ | -.219 $(10^{-2})$ | .000 |
| 612 - 627 | .000 | .6166 | .839 |
| 627 - 696 | -.224 $(10^{-1})$ | -.224 $(10^{-2})$ | .000 |
| 696 - 698 | .000 | .37 | .000 |
| 698 - 768 | -.190 $(10^{-1})$ | -.190 $(10^{-2})$ | .000 |
| 768 - 792 | .000 | .0021 | .000 |
| 792 - 816 | -226 $(10^{-1})$ | -.226 $(10^{-2})$ | .000 |
| 816 - 840 | .000 | .0504 | .000 |
| 840 - 864 | -.227 $(10^{-1})$ | -.227 $(10^{-2})$ | .000 |
| 864 - 888 | -.198 $(10^{-1})$ | -.198 $(10^{-2})$ | .000 |
| 888 - 915 | -.191 $(10^{-1})$ | -.191 $(10^{-1})$ | .000 |

Table 55. Measured bulk density, water content, electrical conductivity, and ion concentration profiles for conditions of Case #1.

| Depth (cm) | Bulk Density | Water Content (θ) | EC (µmho/cm) | Total Salts (meq/1) | Calcium (meq/1) | Magnesium (meq/1) | Sodium (meq/1) | Chloride (meq/1) |
|---|---|---|---|---|---|---|---|---|
| 0 - 5.1 | 1.15 | 0.346 | 866 | 9.3 | 4.4 | 2.9 | 2.0 | 0.6 |
| 5.1 - 10.2 | 1.16 | 0.353 | 744 | 8.5 | 4.3 | 2.6 | 1.7 | 0.3 |
| 10.2 - 15.2 | 1.20 | 0.353 | 852 | 11.9 | 4.4 | 4.4 | 3.2 | 0.3 |
| 15.2 - 20.3 | 1.19 | 0.350 | 1100 | 12.4 | 4.6 | 6.0 | 1.7 | 1.5 |
| 20.3 - 25.4 | 1.19 | 0.348 | 2410 | 24.4 | 9.0 | 13.1 | 2.3 | 16.1 |
| 25.4 - 30.5 | 1.21 | 0.340 | 3162 | 29.8 | 10.9 | 16.5 | 2.5 | 23.6 |
| 30.5 - 35.6 | 1.17 | 0.331 | 3448 | 38.8 | 14.1 | 21.8 | 2.9 | 24.6 |
| 35.6 - 40.6 | 1.14 | 0.332 | 5440 | 58.8 | 21.0 | 34.4 | 3.4 | 46.7 |
| 40.6 - 45.7 | 1.17 | 0.326 | 6000 | 79.1 | 27.5 | 46.9 | 4.7 | 52.9 |
| 45.7 - 50.8 | 1.14 | 0.322 | 7190 | 94.2 | 31.5 | 56.3 | 6.5 | 64.3 |
| 50.8 - 55.9 | 1.15 | 0.300 | 6524 | 90.2 | 30.6 | 53.8 | 5.8 | 52.6 |
| 55.9 - 61.0 | 1.15 | 0.281 | 13840 | 167.3 | 41.9 | 114.9 | 10.5 | 144.0 |

Table 56. Measured bulk density, water content, electrical conductivity, and ion concentration profiles for conditions of Case #2.

| Depth (cm) | Bulk Density | Water Content (θ) | EC (μmho/cm) | Total Salts (meq/l) | Calcium (meq/l) | Magnesium (meq/l) | Sodium (meq/l) | Chloride (meq/l) |
|---|---|---|---|---|---|---|---|---|
| 0 - 5.1 | 1.10 | 0.397 | 379 | 4.4 | 1.6 | 0.6 | 2.2 | 0.2 |
| 5.1 - 10.2 | 1.12 | 0.386 | 552 | 6.4 | 2.6 | 1.1 | 2.7 | 0.3 |
| 10.2 - 15.2 | 1.15 | 0.405 | 1894 | 26.2 | 12.3 | 8.9 | 5.0 | 7.3 |
| 15.2 - 20.3 | 1.15 | 0.40 | 6612 | 84.3 | 36.3 | 26.7 | 11.4 | 54.3 |
| 20.3 - 25.4 | 1.15 | 0.377 | 8064 | 98.2 | 45.0 | 38.3 | 14.9 | 82.5 |
| 25.4 - 30.5 | 1.10 | 0.267 | 6480 | 61.2 | 29.4 | 23.5 | 8.3 | 47.5 |
| 30.5 - 35.6 | 1.22 | 0.396 | 4836 | 43.6 | 20.6 | 16.4 | 6.6 | 22.0 |
| 35.6 - 40.6 | 1.18 | 0.397 | 12031 | 142.2 | 61.9 | 52.1 | 28.3 | 87.8 |
| 40.6 - 45.7 | 1.15 | 0.385 | 8252 | 75.9 | 39.4 | 26.7 | 9.9 | 68.0 |
| 45.7 - 50.8 | 1.12 | 0.370 | 10186 | 125.0 | 62.5 | 54.2 | 8.3 | 104.0 |
| 50.8 - 55.9 | 1.13 | 0.359 | 9590 | 90.1 | 47.4 | 35.4 | 7.3 | 86.5 |
| 55.9 - 61.0 | 1.13 | 0.324 | 9230 | 115.3 | 59.1 | 49.6 | 6.6 | 81.8 |

Table 57. Measured bulk density, water content, electrical conductivity, and ion concentration profiles for conditions of Case #3.

| Depth (cm) | Bulk Density | Water Content (θ) | EC (μmho/cm) | Total Salts (meq/l) | Calcium (meq/l) | Magnesium (meq/l) | Sodium (meq/l) | Chloride (meq/l) |
|---|---|---|---|---|---|---|---|---|
| 0 - 5.1 | 1.11 | 0.376 | 1408 | 20.8 | 12.2 | 4.0 | 4.6 | 2.9 |
| 5.1 - 10.2 | 1.13 | 0.388 | 6090 | 77.0 | 16.5 | 5.7 | 54.8 | 33.5 |
| 10.2 - 15.2 | 1.12 | 0.376 | 11040 | 128.2 | 50.0 | 36.9 | 41.3 | 100.4 |
| 15.2 - 20.3 | 1.16 | 0.394 | 7372 | 76.5 | 38.5 | 20.0 | 18.0 | 52.2 |
| 20.3 - 25.4 | 1.16 | 0.412 | 6532 | 78.0 | 38.0 | 22.4 | 17.6 | 43.9 |
| 25.4 - 30.5 | 1.16 | 0.404 | 5745 | 63.2 | 29.3 | 20.2 | 13.7 | 34.5 |
| 30.5 - 35.6 | 1.18 | 0.416 | 5320 | 61.4 | 29.5 | 17.1 | 14.8 | 29.0 |
| 35.6 - 40.6 | 1.16 | 0.419 | 6128 | 70.9 | 34.5 | 22.4 | 14.1 | 35.7 |
| 40.6 - 45.7 | 1.14 | 0.418 | 7380 | 83.0 | 42.0 | 26.3 | 14.7 | 49.9 |
| 45.7 - 50.8 | 1.17 | 0.419 | 10653 | 121.9 | 63.5 | 44.3 | 13.8 | 89.2 |
| 50.8 - 55.9 | 1.17 | 0.451 | 11610 | 126.4 | 70.0 | 48.9 | 7.5 | 101.1 |
| 55.9 - 61.0 | 1.16 | 0.473 | 9379 | 111.4 | 63.5 | 42.0 | 6.4 | 89.5 |

Table 58. Chemical analyses of saturation extract for field experiment.

| Depth (cm) | EC (µmho/cm) | Total Salts (meq/1) | Calcium (meq/1) | Magnesium (meq/1) | Sodium (meq/1) | Chloride (meq/1) |
|---|---|---|---|---|---|---|
| | | | (a) 324 hours | | | |
| 0 - 30 | 3281 | 42.9 | 18.5 | 11.3 | 13.1 | 16.2 |
| 30 - 60 | 6952 | 72.9 | 32.4 | 41.1 | 8.4 | 57.6 |
| 60 - 90 | 2941 | 41.4 | 12.8 | 22.4 | 6.3 | 3.7 |
| 90 - 120 | 3178 | 46.0 | 16.3 | 23.9 | 5.9 | 0.4 |
| | | | (b) 329 hours | | | |
| 0 - 30 | 4571 | 59.1 | 12.3 | 6.9 | 40.0 | 14.1 |
| 30 - 60 | 6996 | 70.6 | 22.5 | 41.7 | 6.4 | 51.9 |
| 60 - 90 | 4562 | 48.1 | 14.9 | 26.5 | 6.6 | 13.8 |
| 90 - 120 | 3670 | 47.9 | 14.3 | 27.2 | 6.4 | 2.5 |
| | | | (c) 627 hours | | | |
| 0 - 30 | 6468 | 73.0 | 21.1 | 6.7 | 45.2 | 40.2 |
| 30 - 60 | 8981 | 88.6 | 46.7 | 33.2 | 8.7 | 78.1 |
| 60 - 90 | 7260 | 73.6 | 34.1 | 34.8 | 4.8 | 53.3 |
| 90 - 120 | 4462 | 52.8 | 30.6 | 17.7 | 4.6 | 16.4 |

Table 59. Water content (θ) profiles for salt flow field experiment.

| Depth (cm) | Time<br>24 hrs | 40 hrs | 324 hrs | 339 hrs | 627 hrs |
|---|---|---|---|---|---|
| 30 | 0.20 | 0.32 | 0.24 | 0.32 | 0.28 |
| 45 | 0.24 | 0.32 | 0.28 | 0.33 | 0.29 |
| 75 | 0.25 | 0.32 | 0.27 | 0.33 | 0.28 |
| 105 | 0.29 | 0.33 | 0.31 | 0.34 | 0.31 |
| 135 | 0.38 | 0.40 | 0.39 | 0.40 | 0.39 |
| 165 | 0.41 | 0.42 | 0.42 | 0.42 | 0.41 |

Table 60. Electrical conductivity (μmho/cm) profiles at the field water content for the salt flow field experiment.

| Depth (cm) | Time<br>24 hrs | 48 hrs | 76 hrs | 324 hrs | 327 hrs | 627 hrs |
|---|---|---|---|---|---|---|
| 15 | - | 4082 | 3740 | 6915 | 8747 | 8883 |
| 45 | 3369 | 33657 | 32422 | 15070 | 14745 | 14350 |
| 75 | 4068 | 4252 | 13877 | 7032 | 7175 | 9285 |
| 105 | 3111 | 6686 | 6382 | 3930 | 4410 | 4756 |
| 135 | 3426 | 3279 | 3012 | 3372 | 3594 | 4373 |
| 165 | 2671 | 2820 | 2765 | 2654 | 2700 | 2622 |

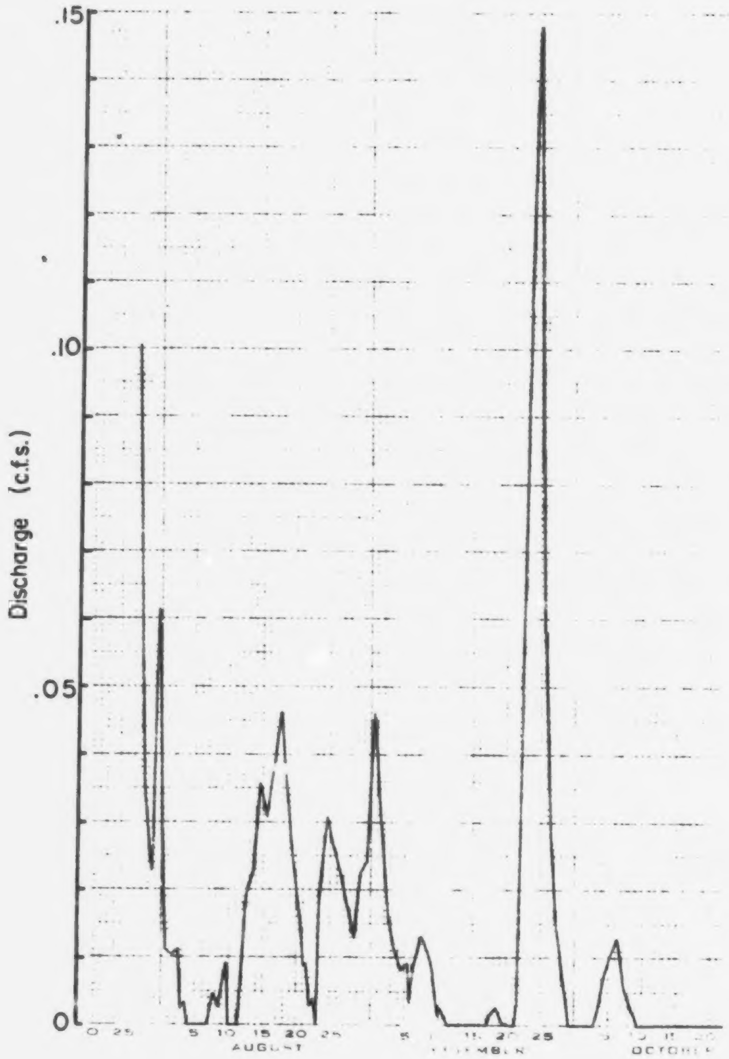

Figure 56. Hydrograph of discharge from drain 4 during 1971.

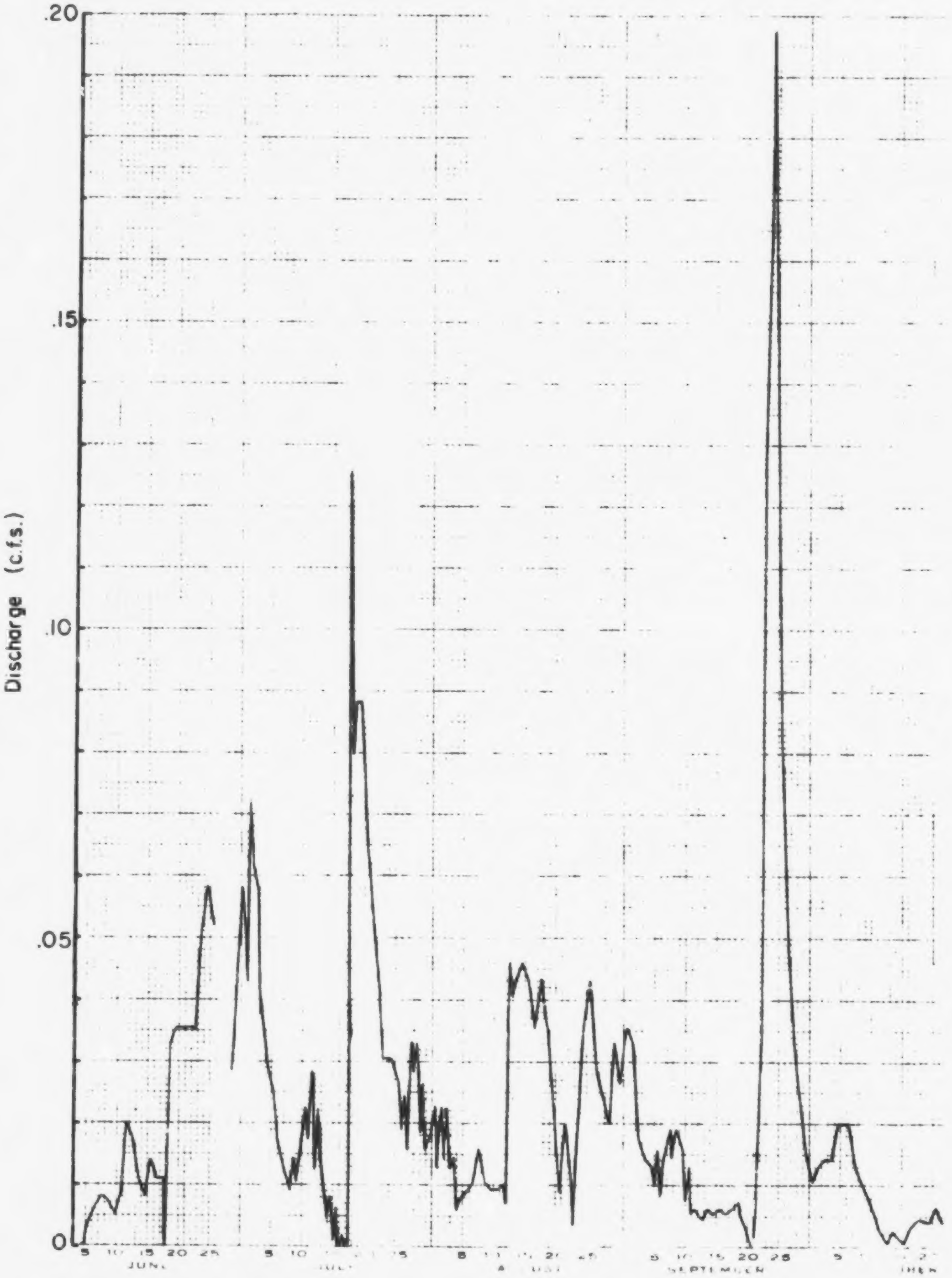

Figure 57. Hydrograph of discharge from drain 5 during 1971.

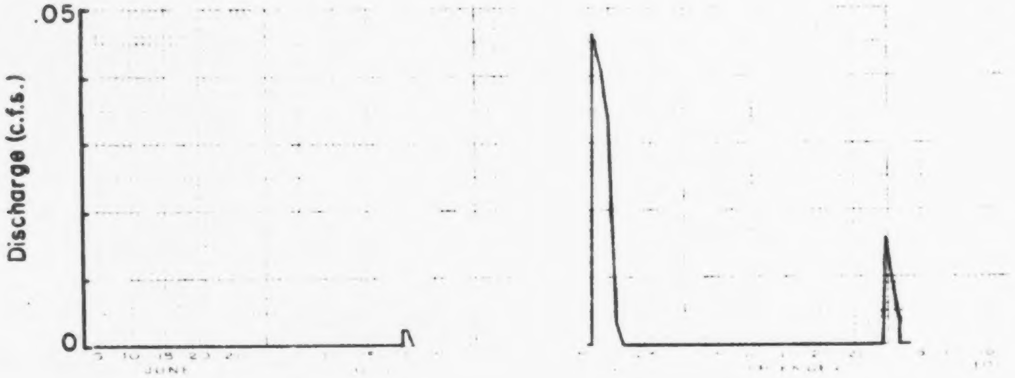

Figure 58. Hydrograph of discharge from drain 3 during 1971.

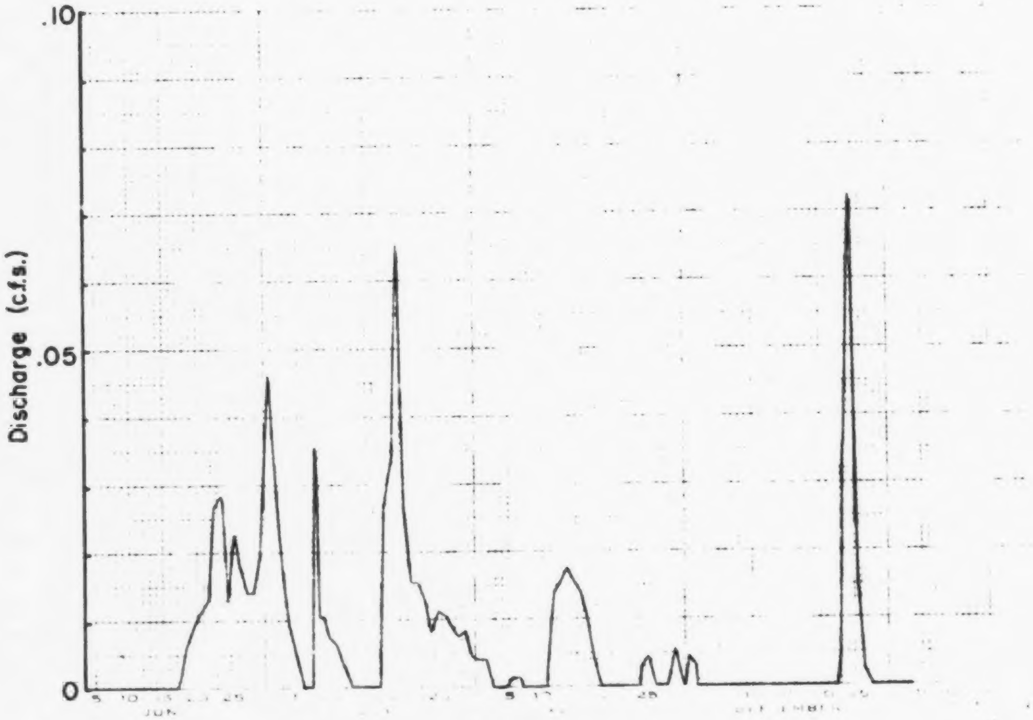

Figure 59. Hydrograph of discharge from drain 6 during 1971.

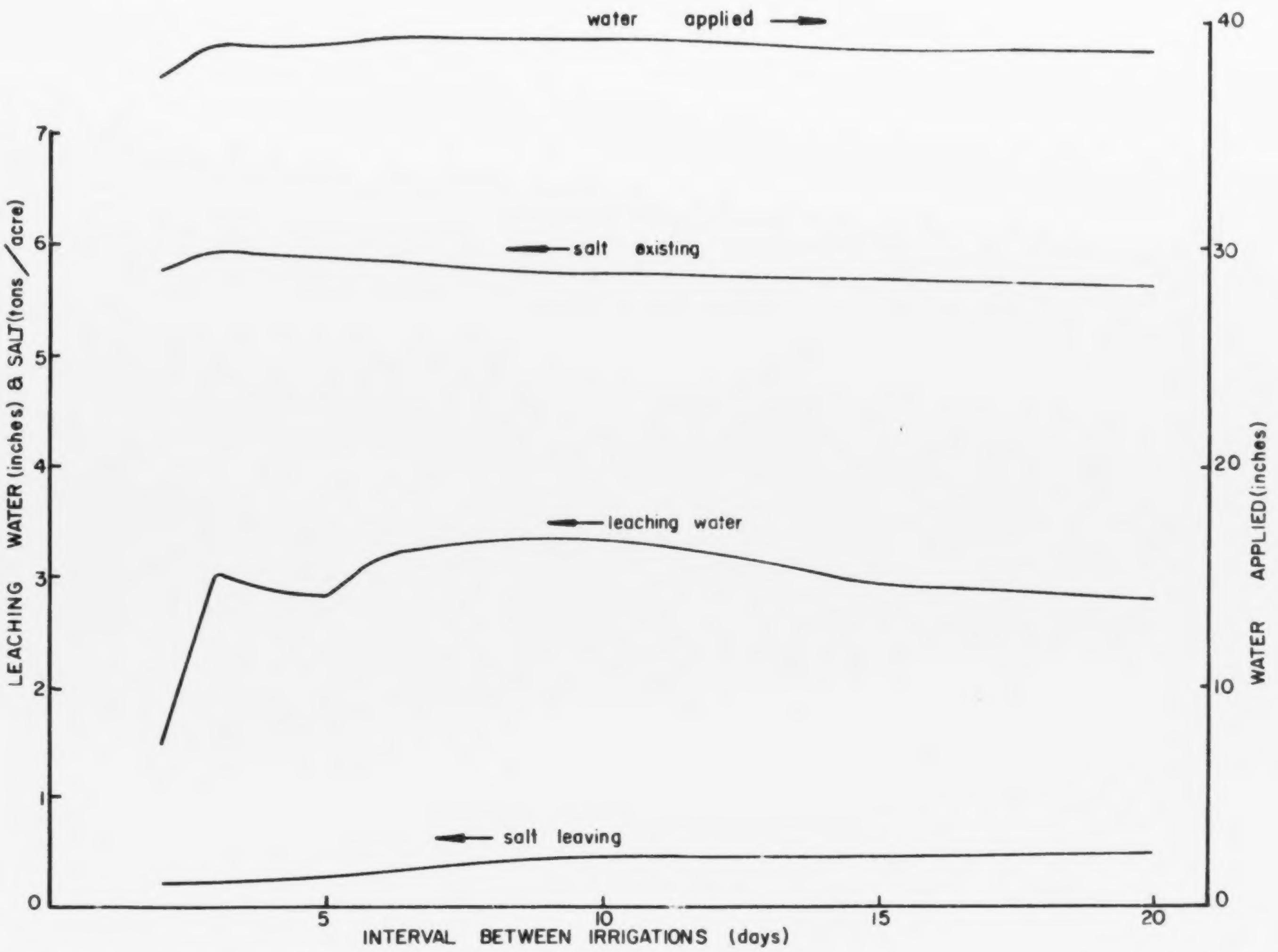

Figure 60. Season total results for problem ACG.

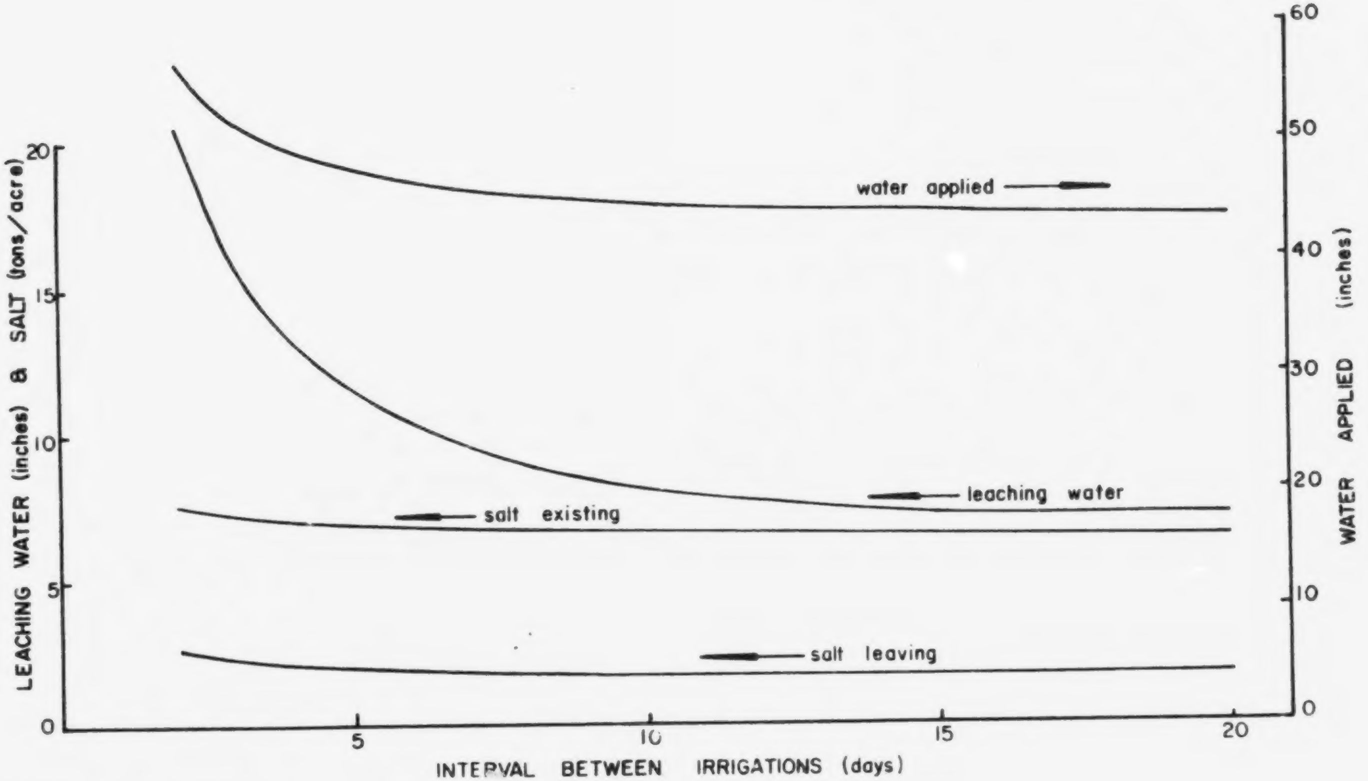

Figure 61. Season total results for problem BCG.

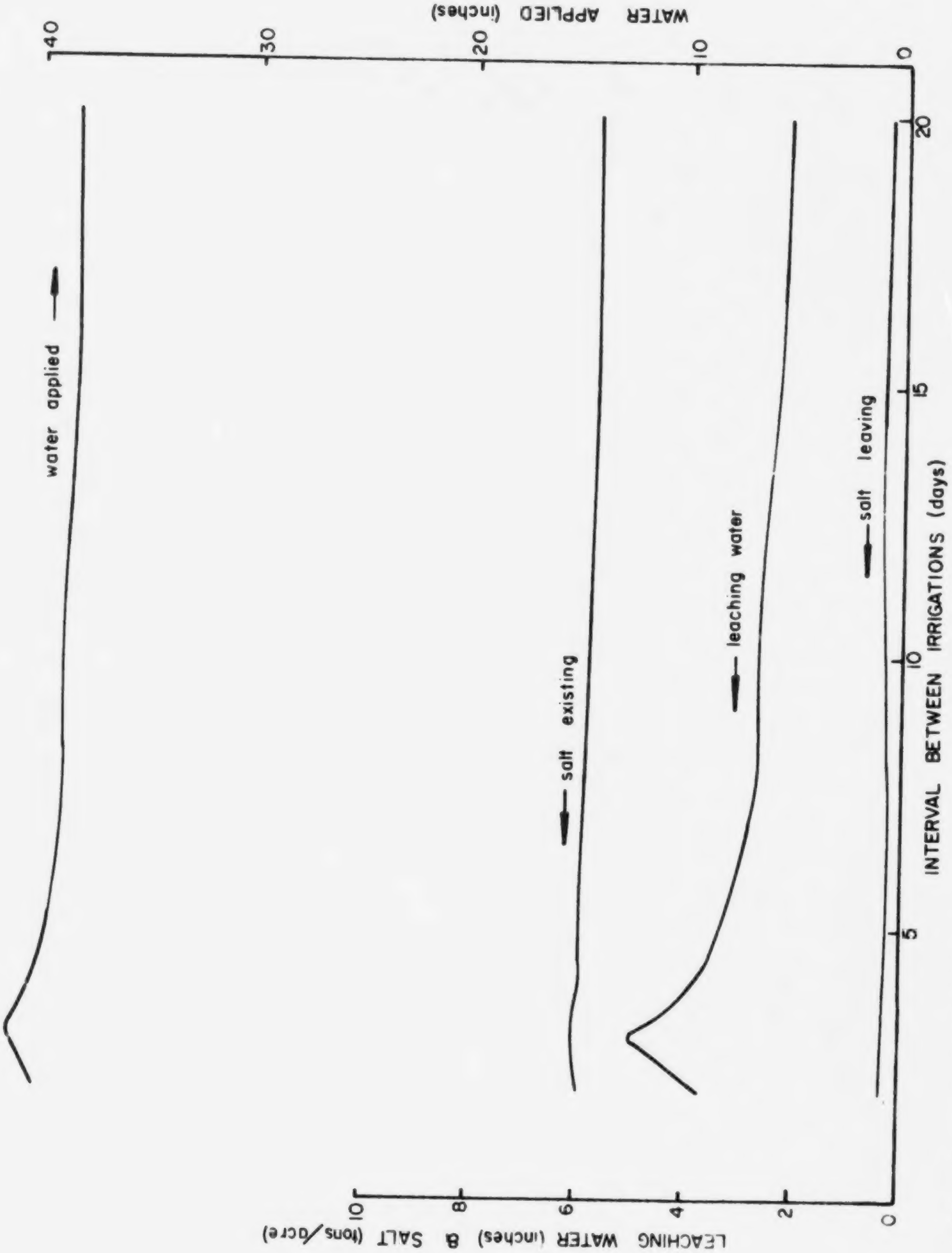

Figure 62. Season total results for problem ACH.

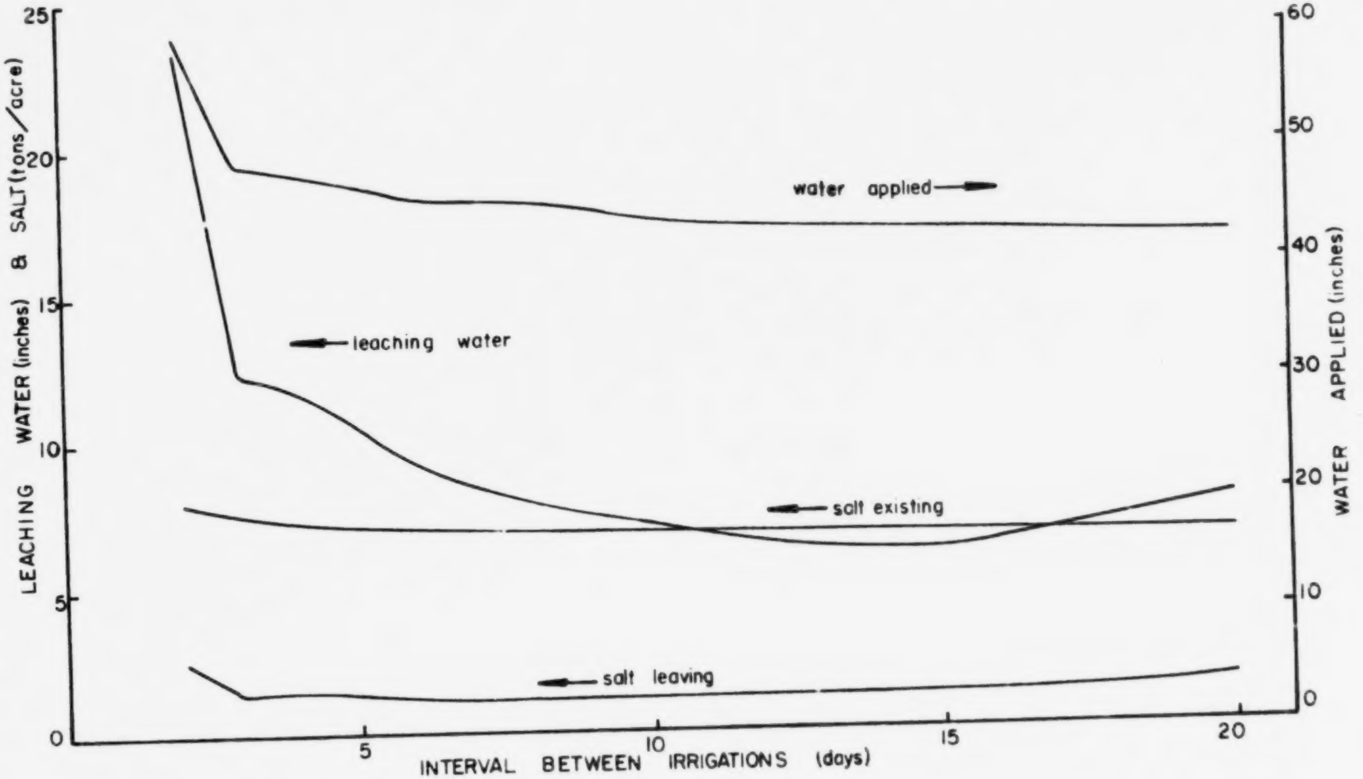

Figure 63. Season total results for problem BCH.

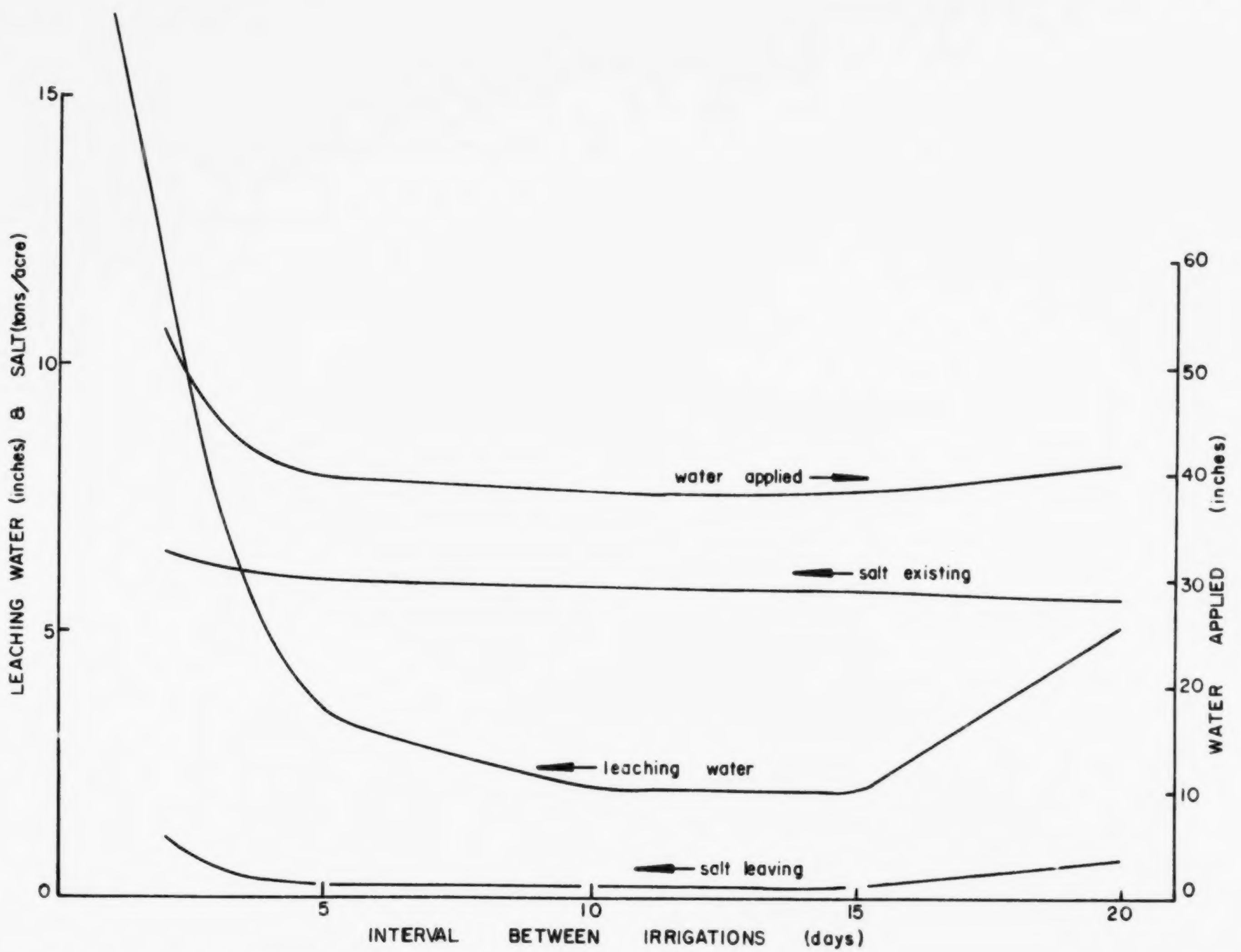

Figure 64. Season total results for problem ACI.

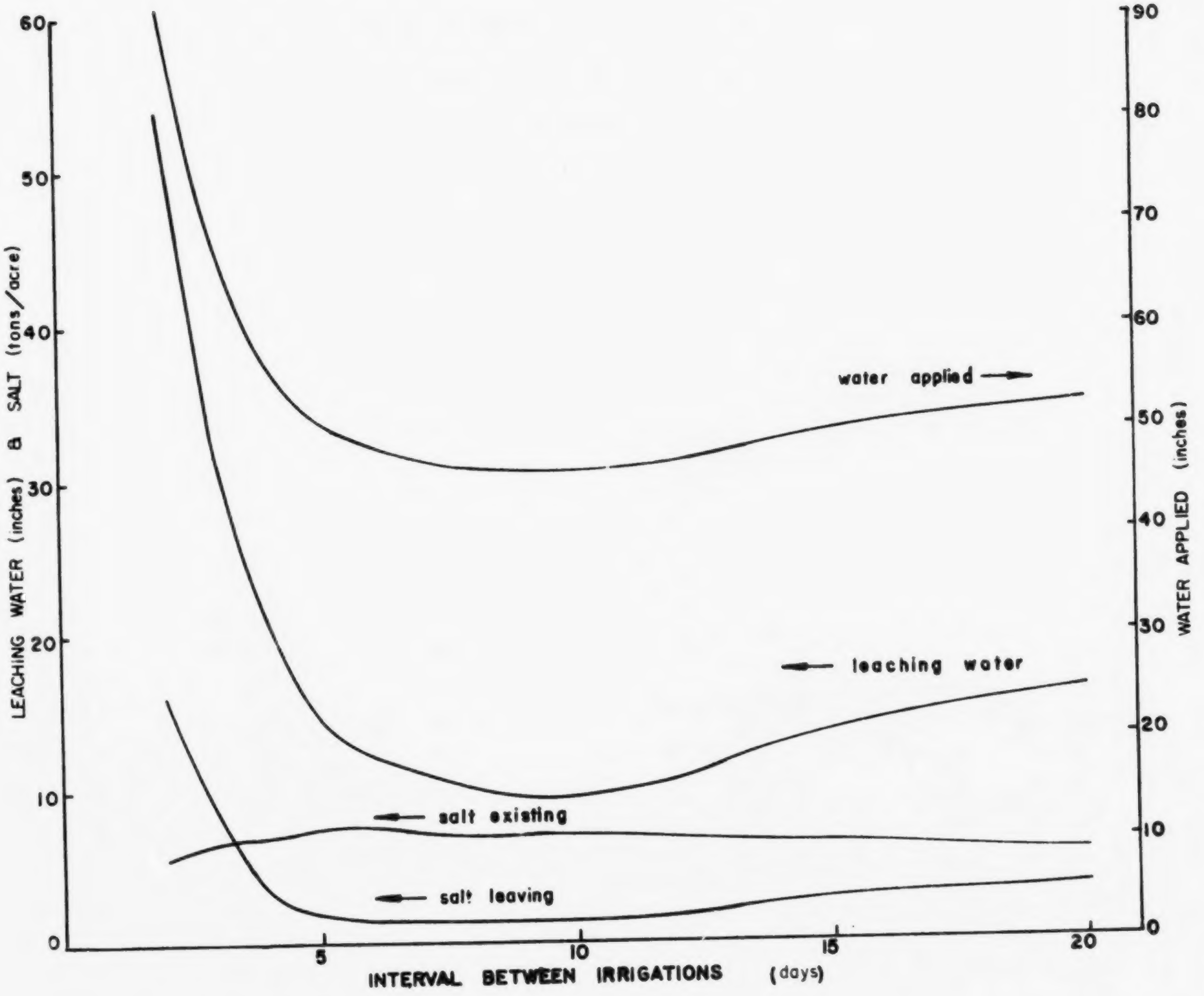

Figure 65. Season total results for problem BCI.

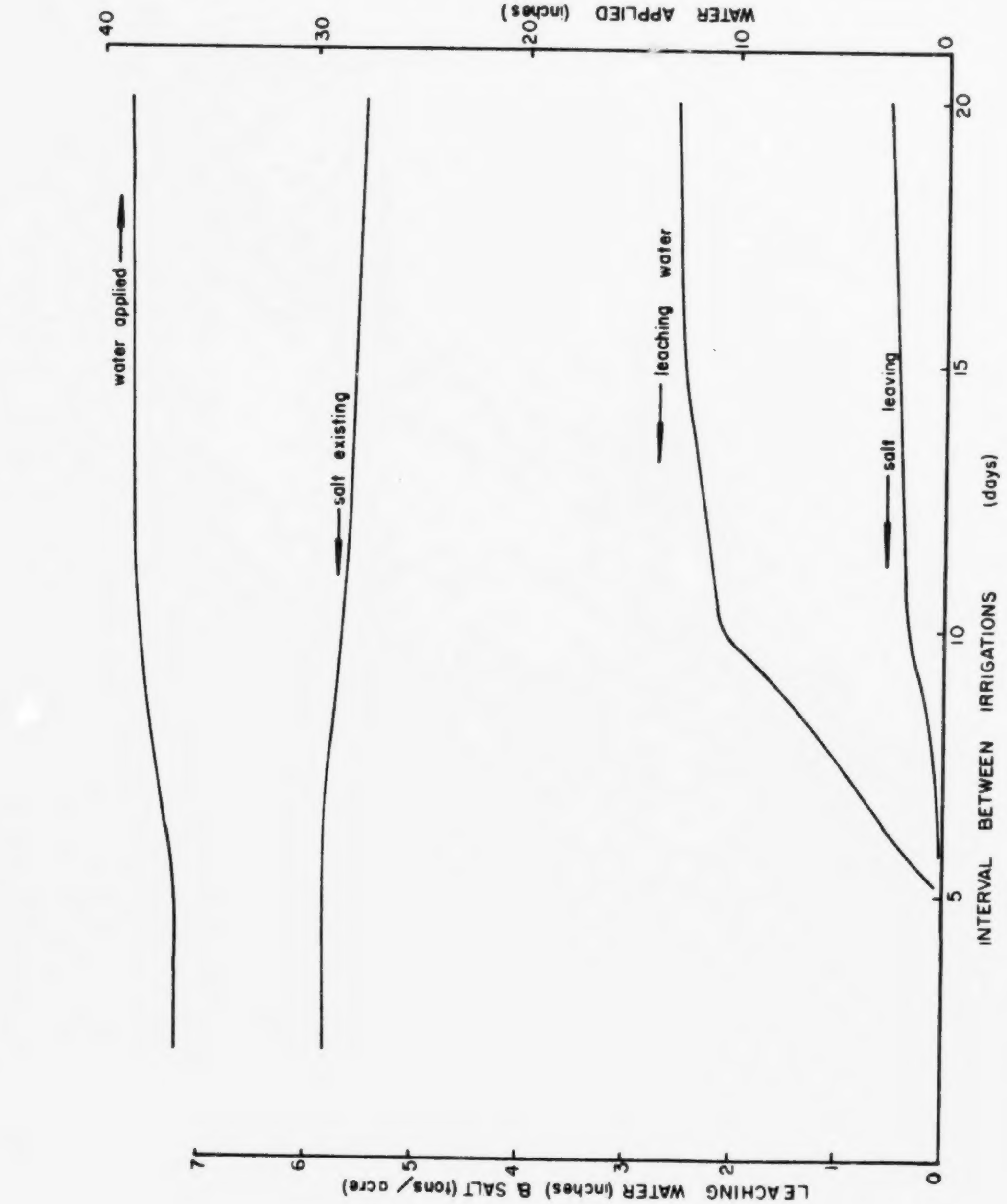

Figure 66. Season total results for problem ADF.

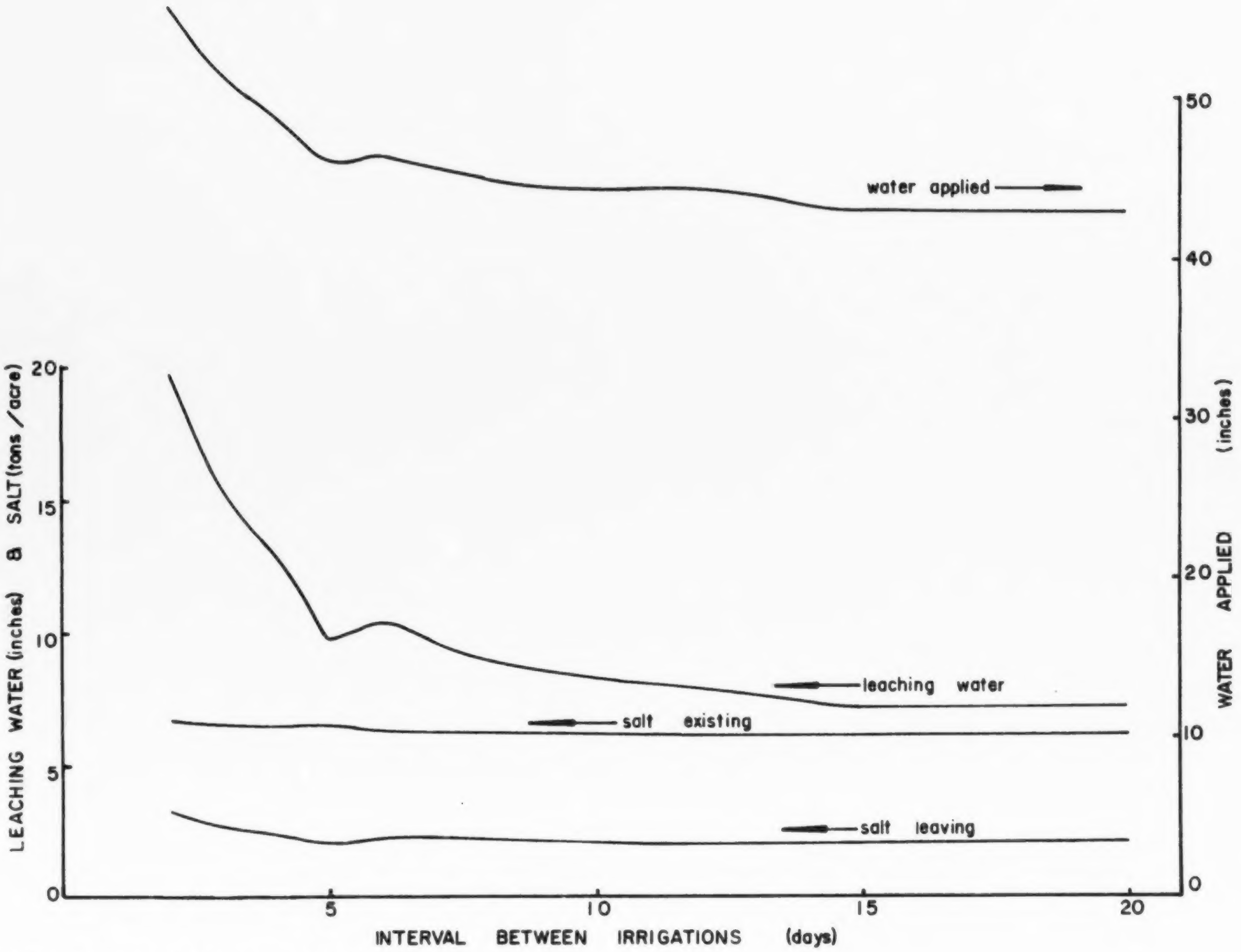

Figure 67. Season total results for problem BDF.

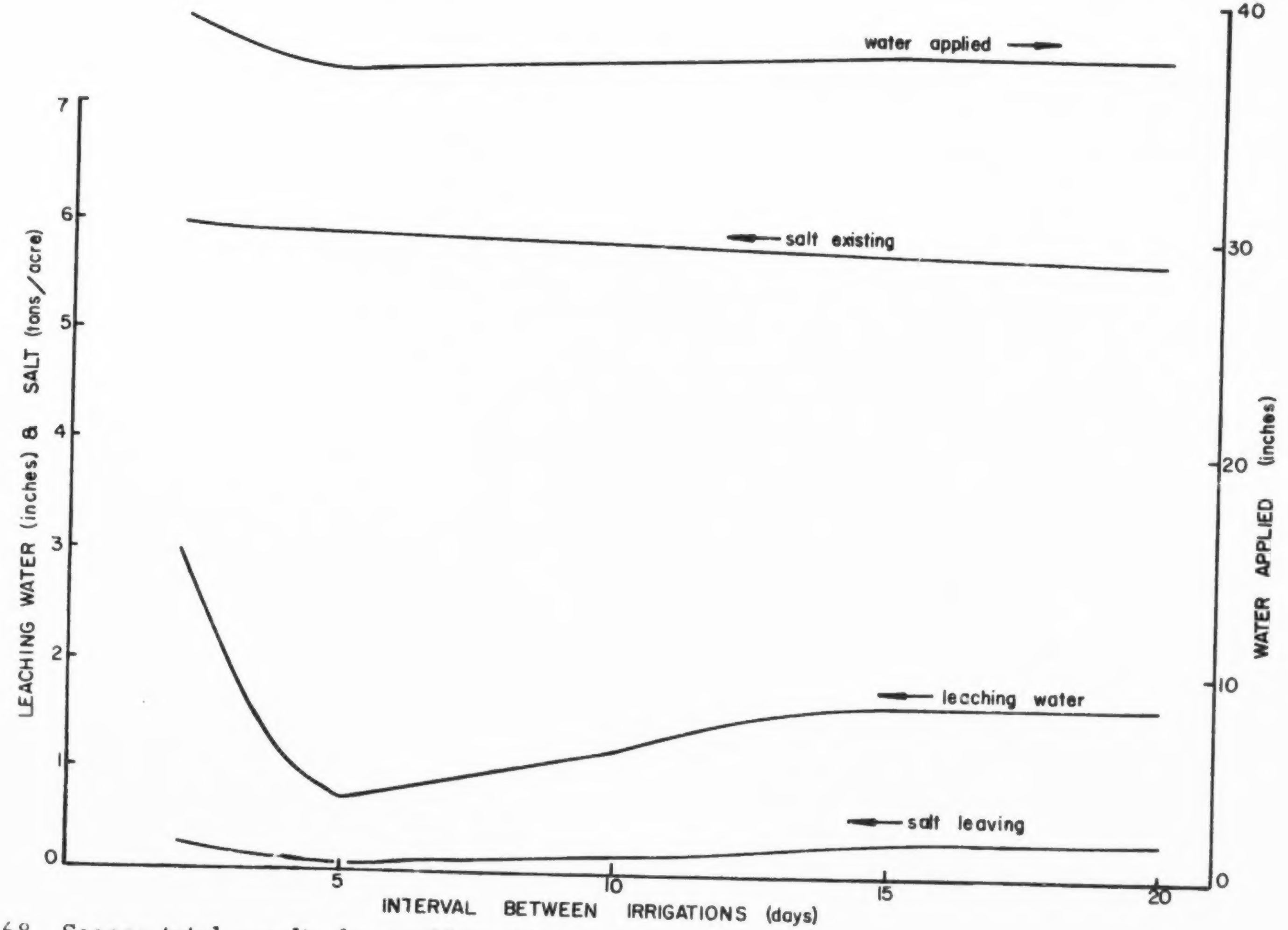

Figure 68. Season total results for problem ADG.

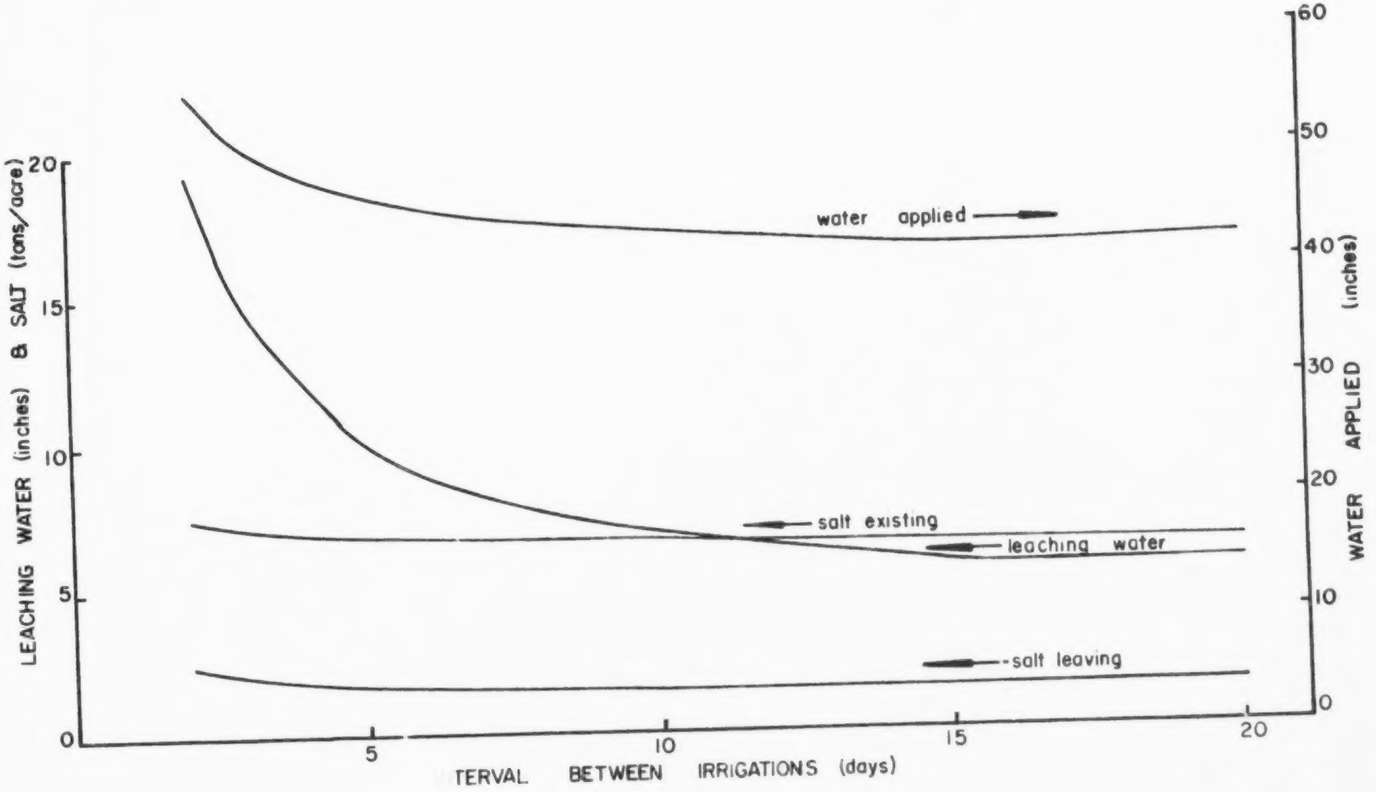

Figure 69. Season total results for problem BDG.

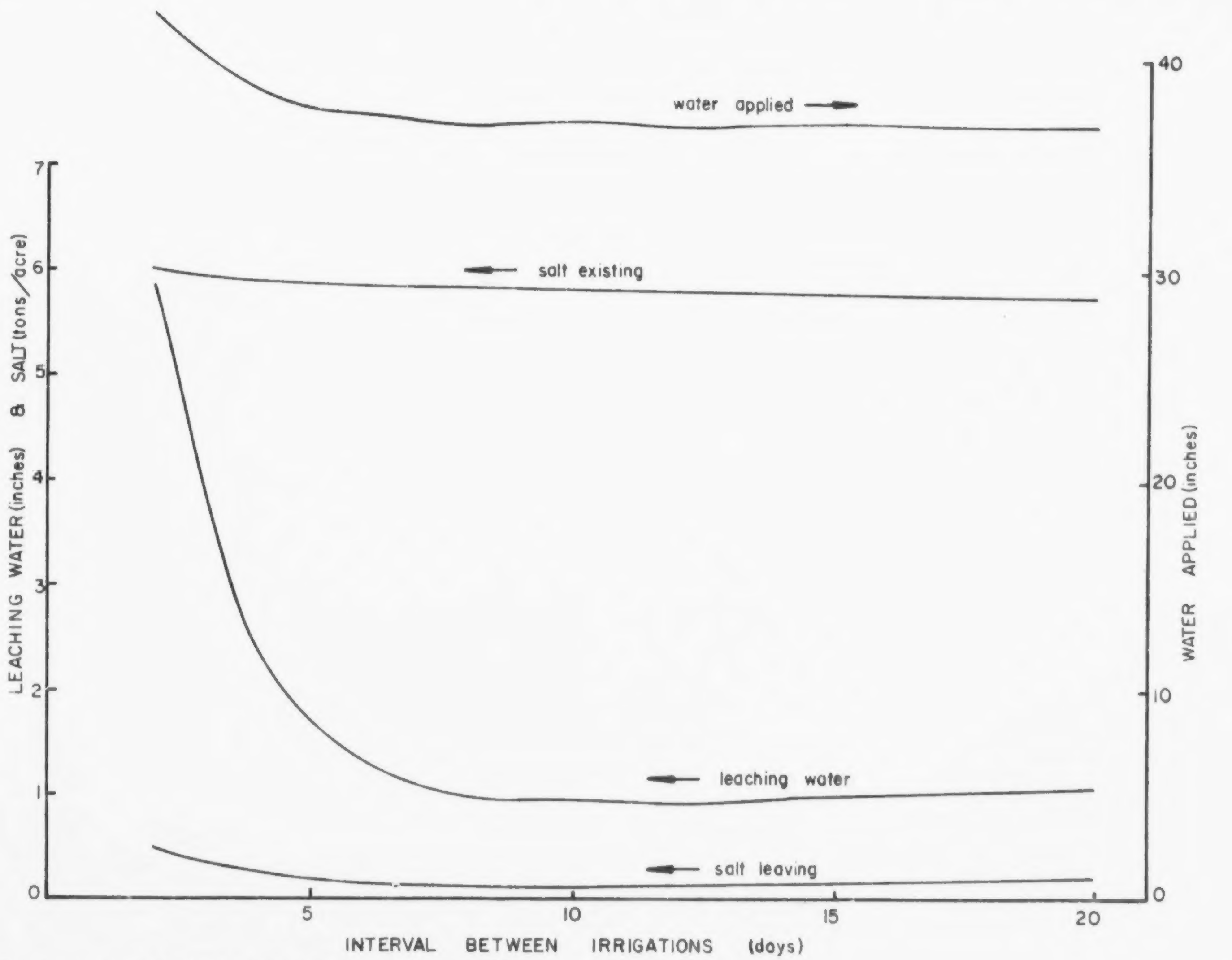

Figure 70. Season total results for problem ADH.

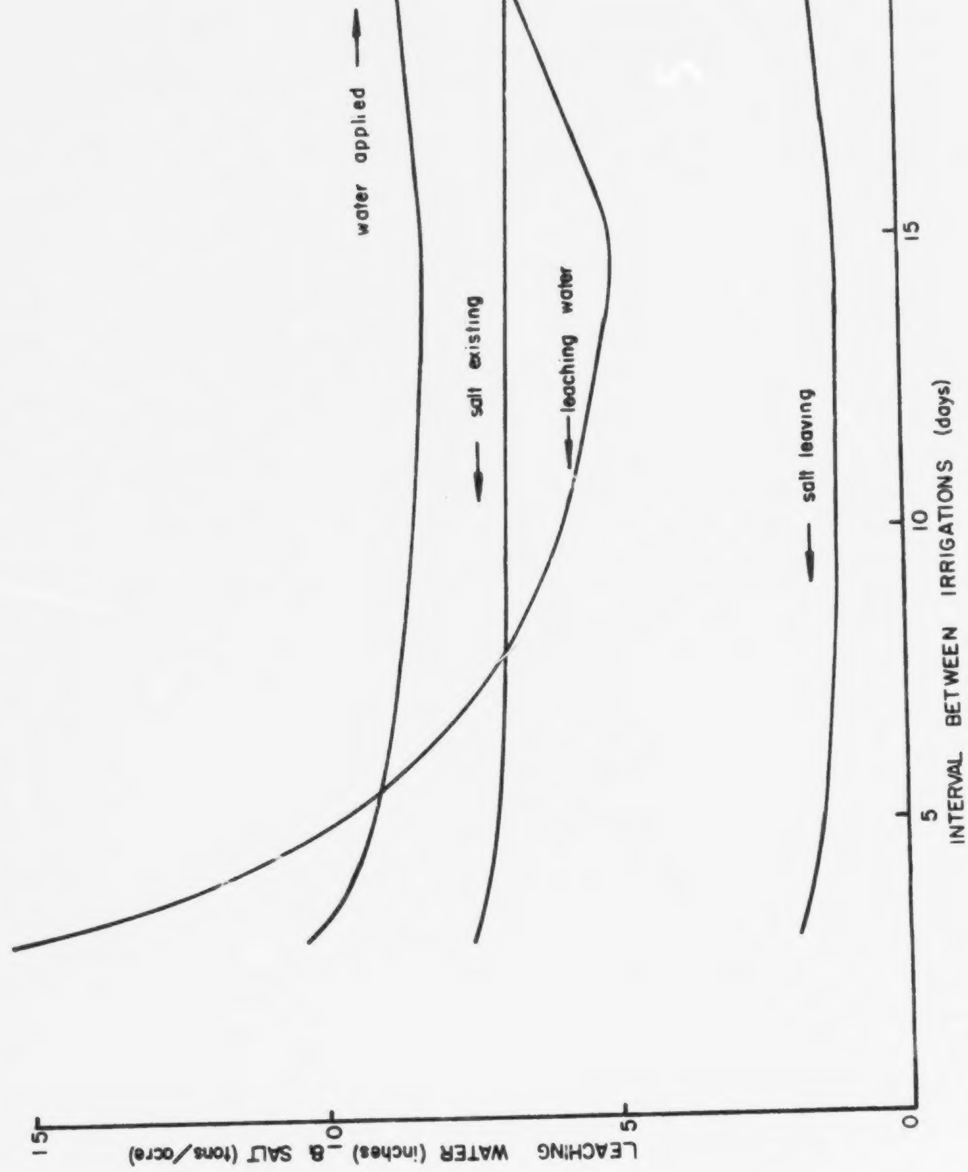

Figure 71. Season total results for problem BDH.

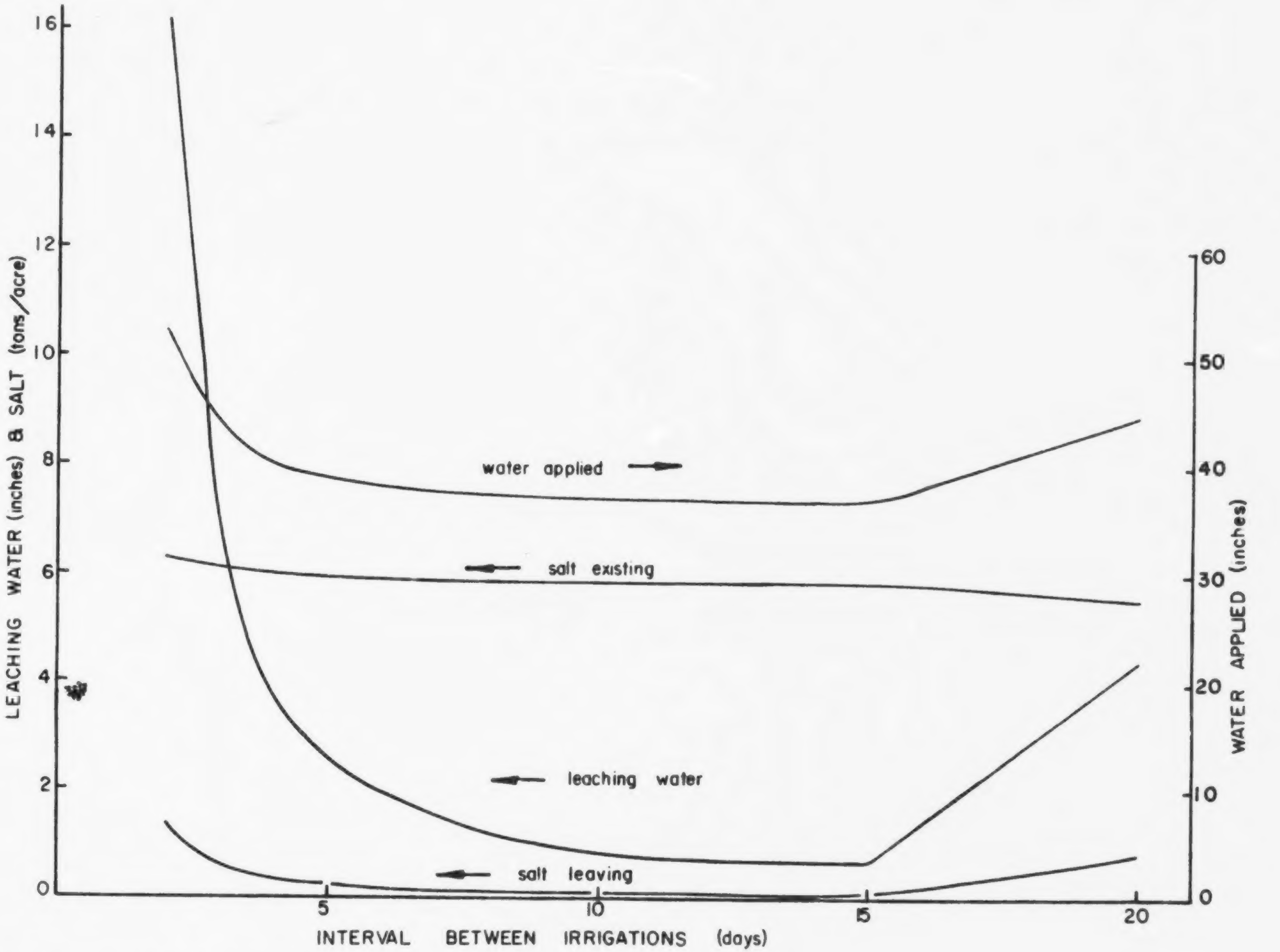

Figure 72. Season total results for problem ADI.

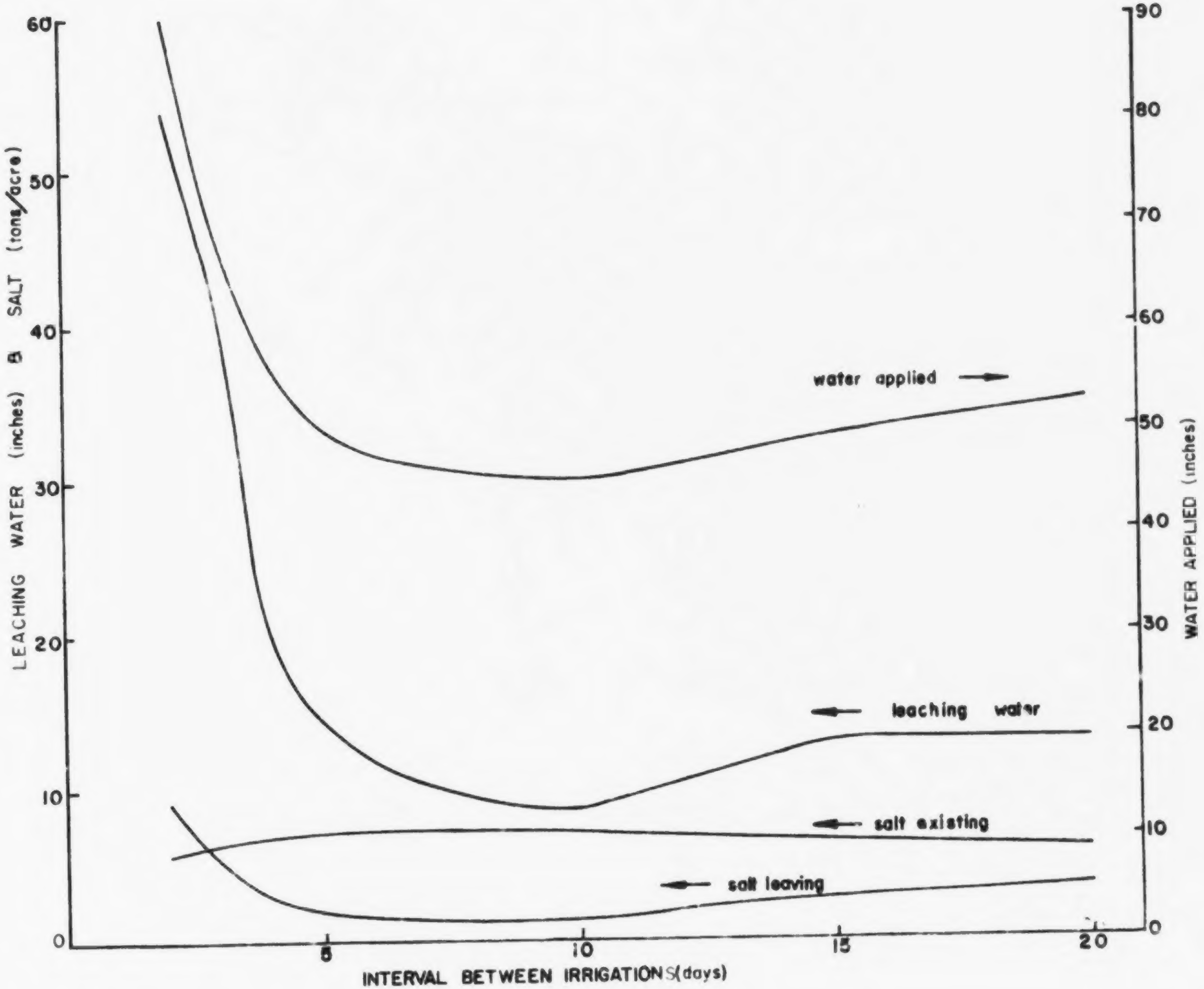

Figure 73. Season total results for problem BDI.

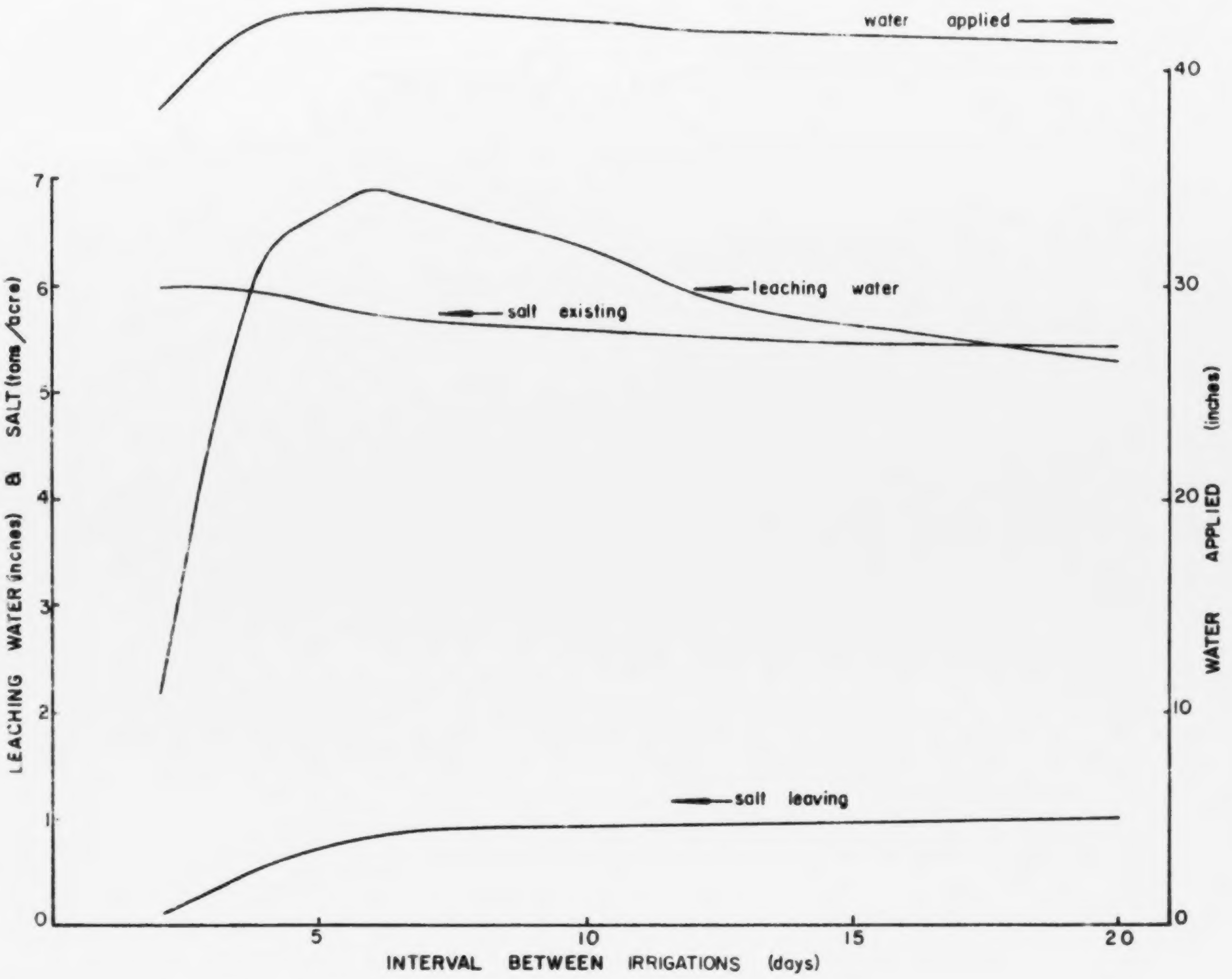

Figure 74. Season total results for problem AEF.

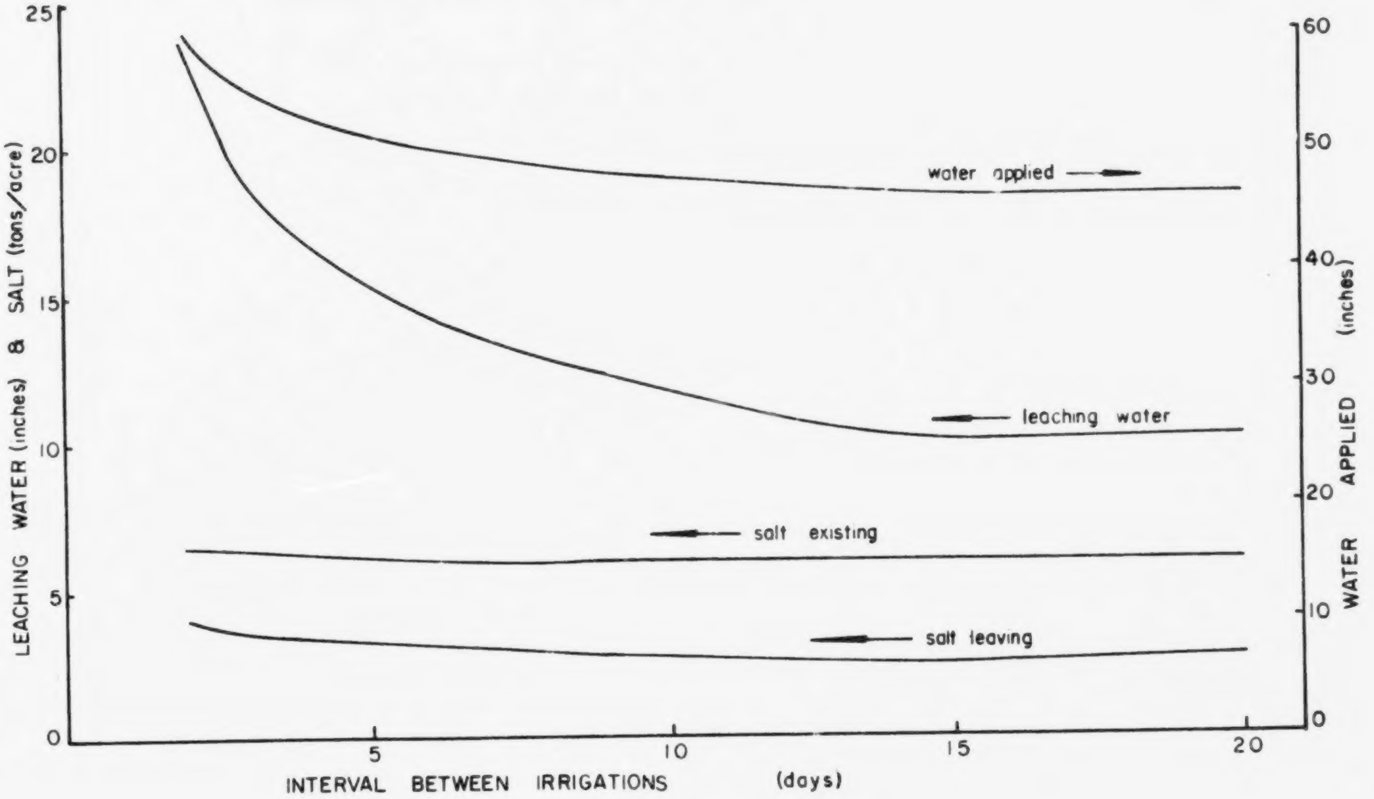

Figure 75. Season total results for problem BEF.

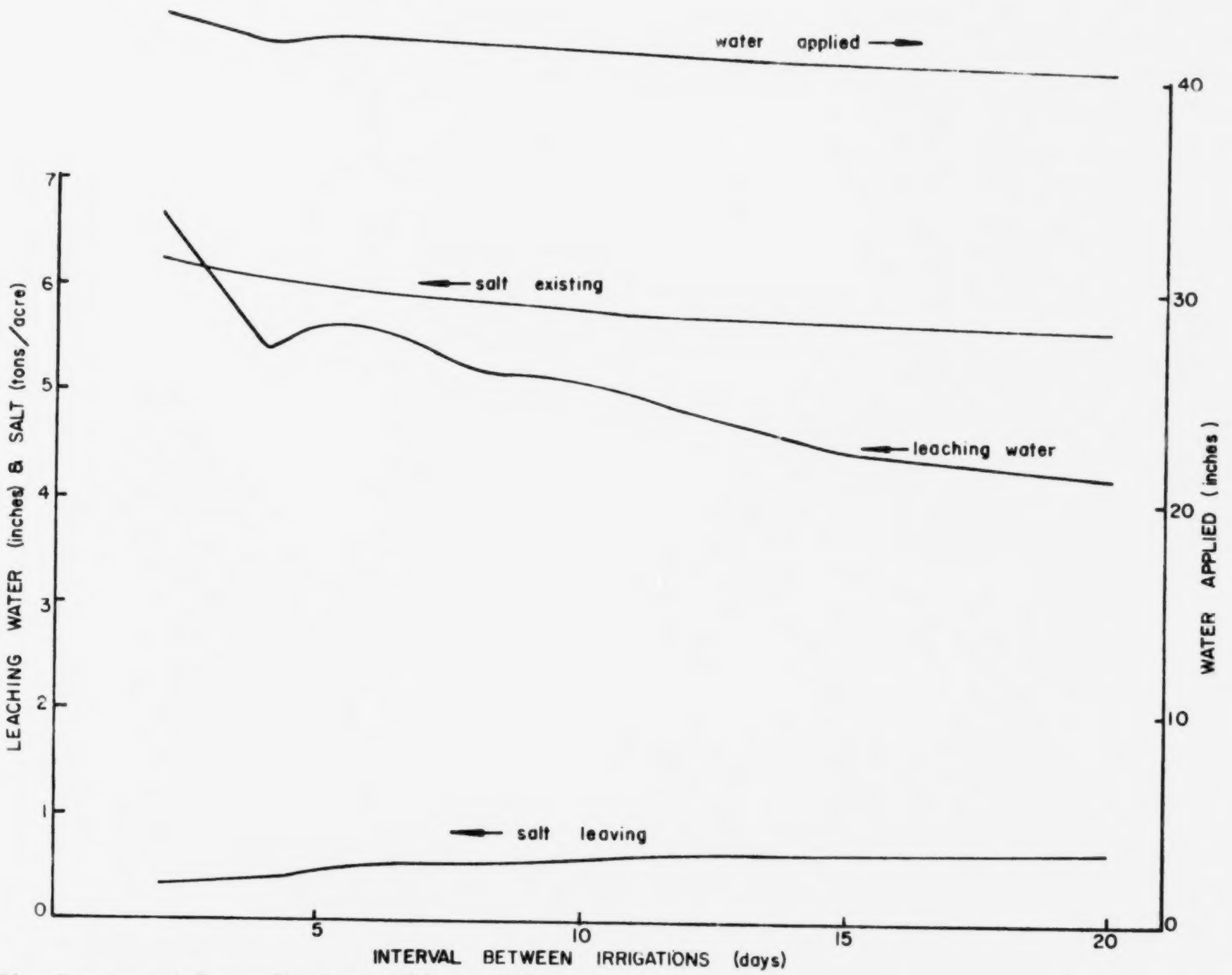

Figure 76. Season total results for problem AEG.

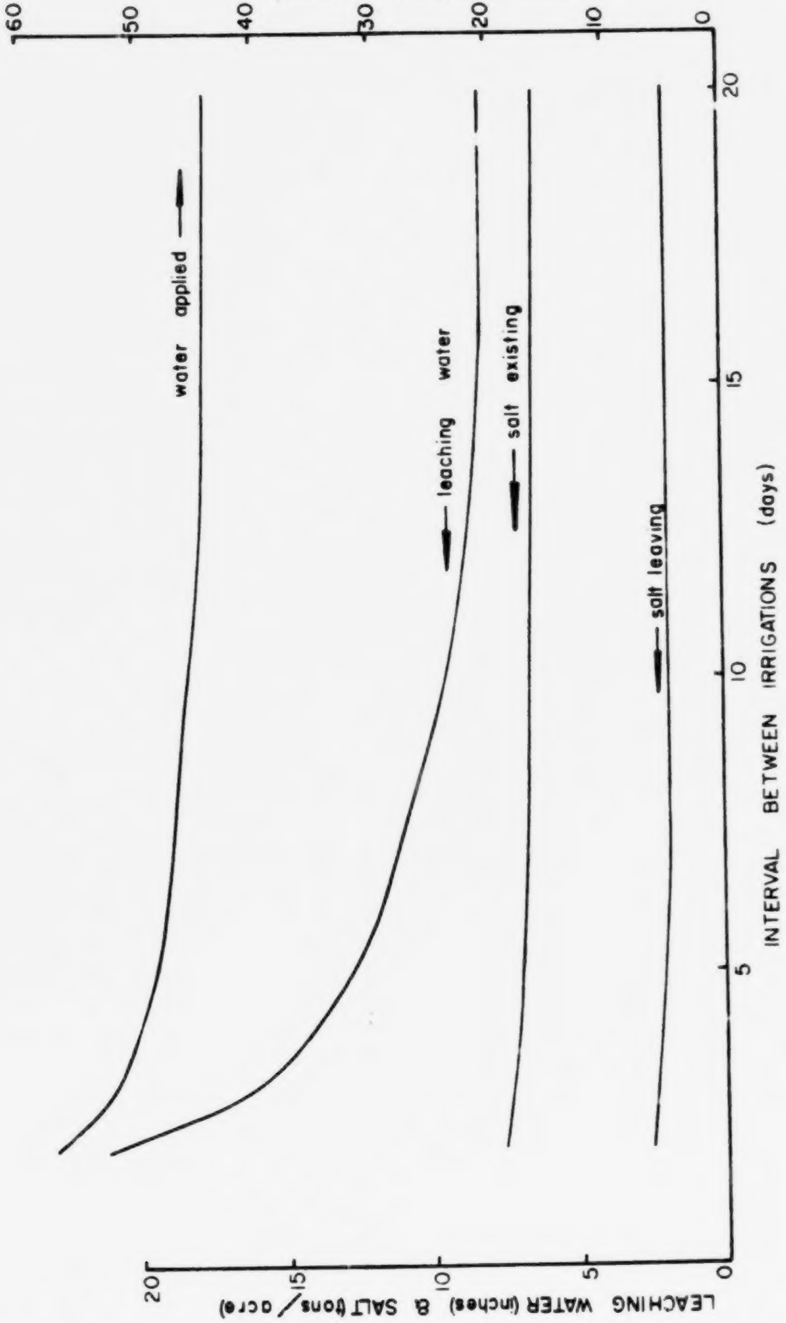

Figure 77. Season total results for problem BEG.

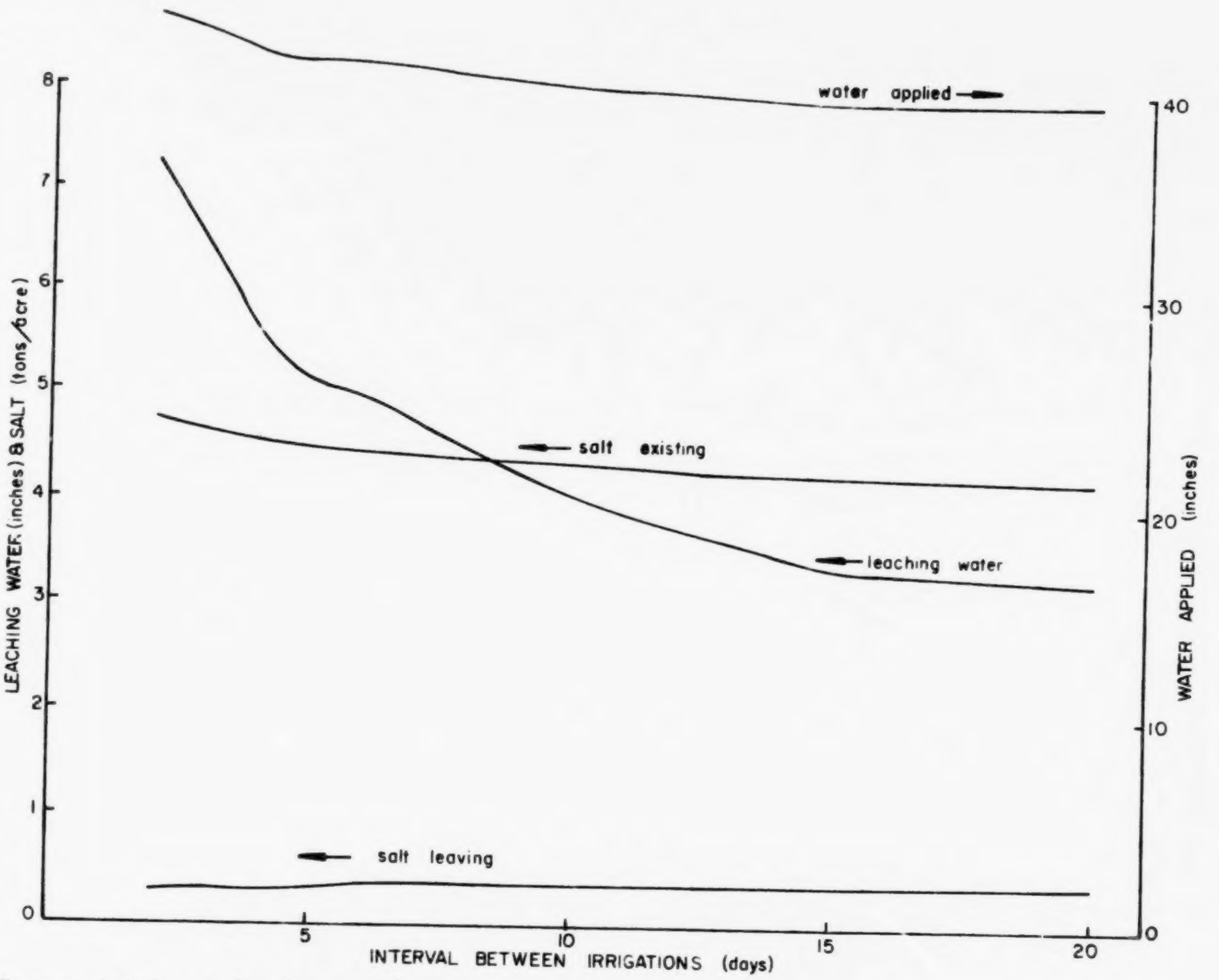

Figure 78. Season total results for problem AEH.

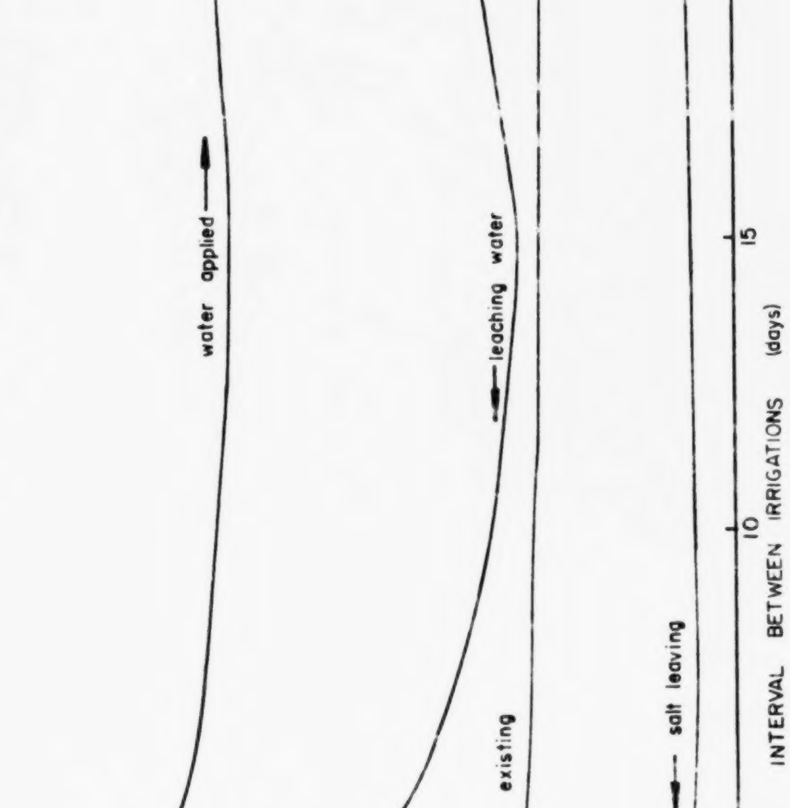

Figure 79. Season total results for problem BEH.

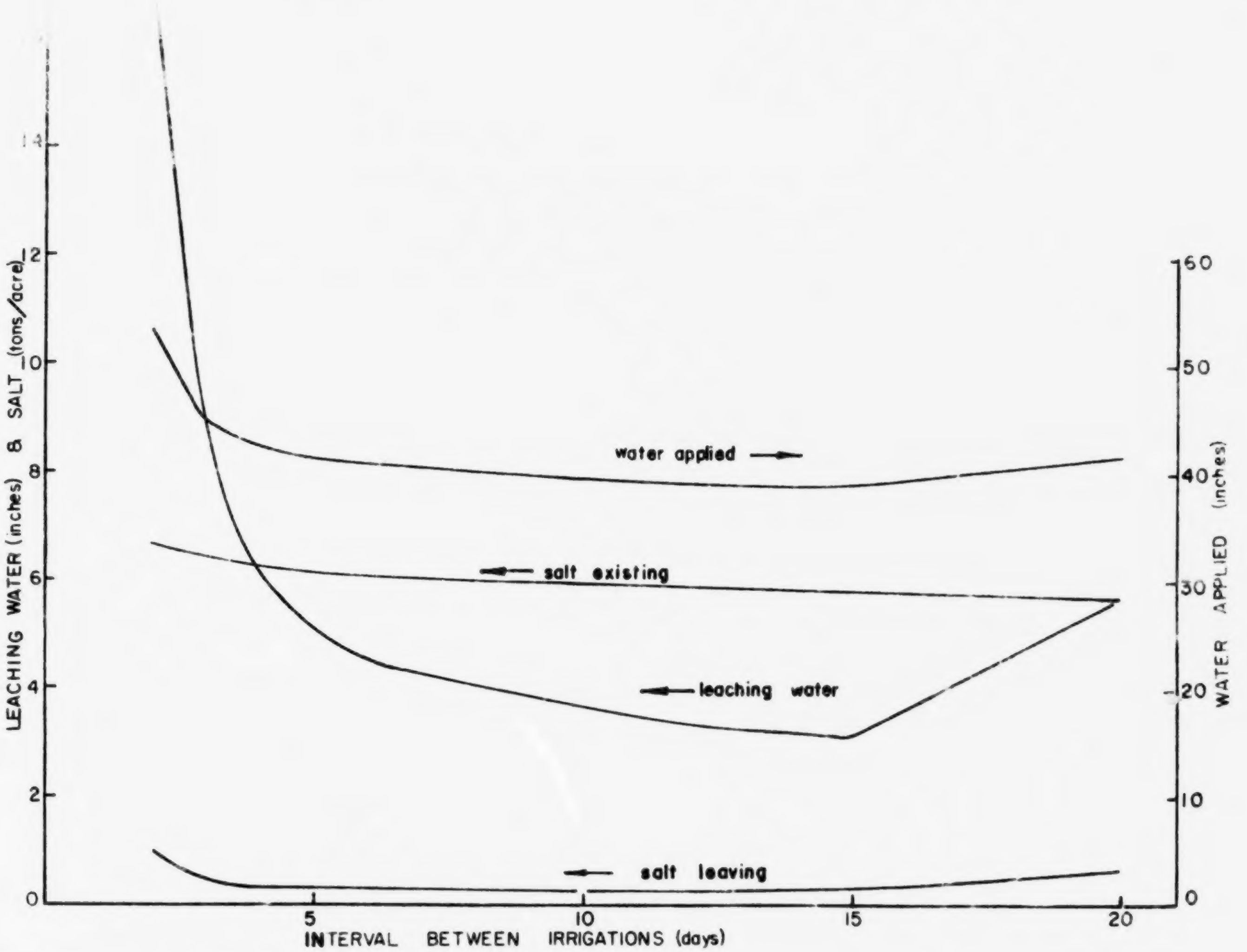

Figure 80. Season total results for problem AEI.

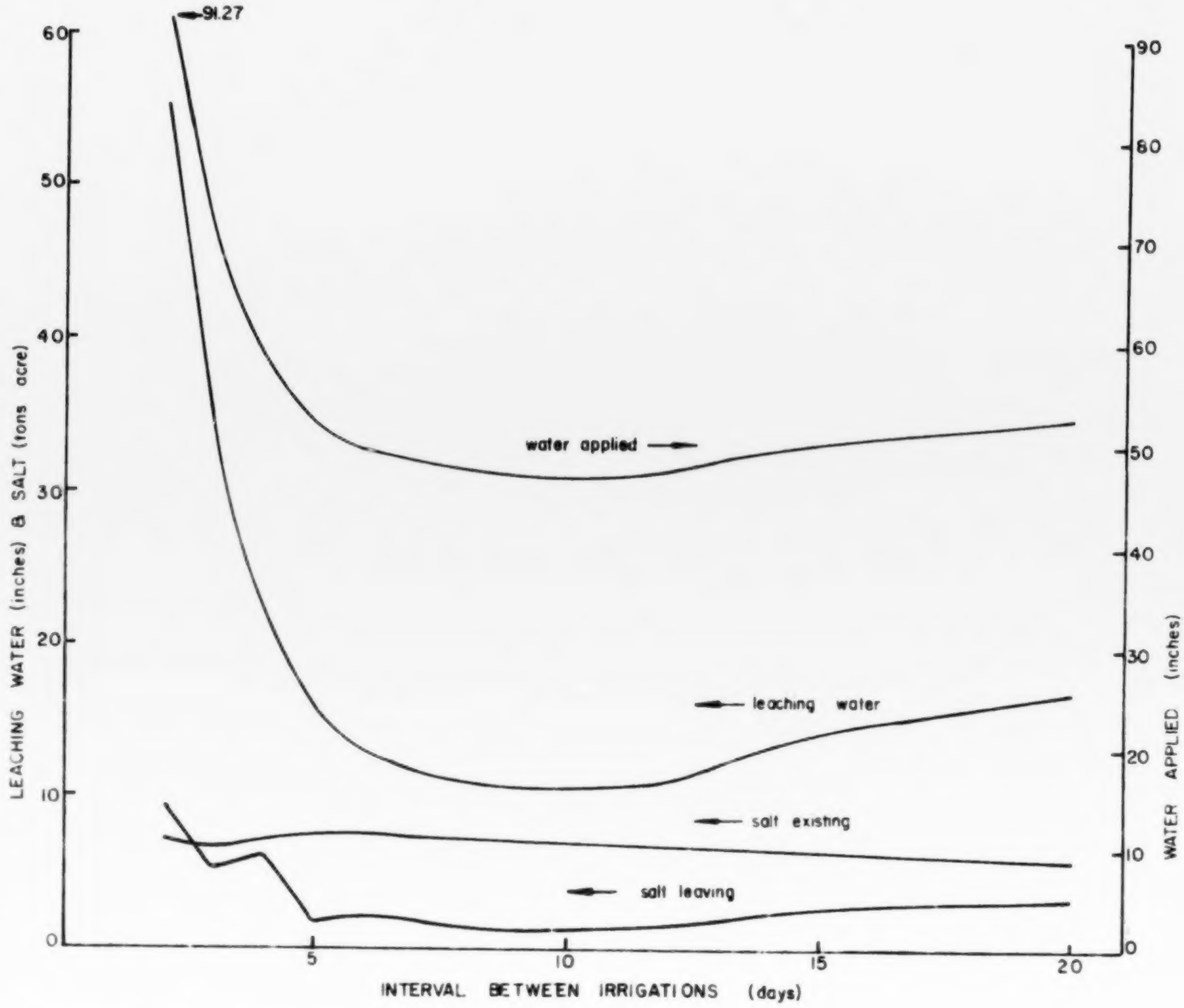

Figure 81. Season total results for problem BEI.